Cummins Surveillance Panel
Teleconference
Meeting Minutes
April 2, 2015

The teleconference convened at 10:30 a.m. EDT

Attendance:
Afton - Bob Campbell, Christian Porter
ChevronOronite - Mark Cooper, Jim Rutherford
Cummins - Dan Nyman
Infineum - Elisa Santos, Pat Fetterman
Intertek - Jim Moritz, Mey Dewey
Lubrizol - Kevin O'Malley, Nick Secue, Michael Conrad
SwRI - Jim McCord, Perry Grosch, Jim Carroll, Martin Thompson
TEI - Zack Bishop
TMC - Jeff Clark, Sean Moyer
Volvo - Greg Shank

New ISB Hardware:
This teleconference is part of the ongoing review of the introduction of new ISB hardware (batch K cams, batch D tappets). On the prior call, Kevin O'Malley was requested to use a modeling approach that would consider hardware batches (tappets and cams), reference oil blends, and fuel batches as part of the analysis. Kevin reviewed his work (attached) for the panel. His general comments are shown on slide number 3, his summaries and correction factor options are shown on slides 28 - 32. The panel was grateful for Kevin's efforts. Elisa Santos also showed some work which helped explain/reduce the collinearity that Kevin noted in his presentation.

After discussion, ***it was moved (McCord, Fetterman) to use a multiplicative correction factor of 1.0 for ATWL for tests run on batch K cams and batch D tappets.*** This motion passed without objection (TEI, TMC waive). The TMC will issue an information letter and an ltms update accordingly.

For ACSW, it was moved (McCord, Fetterman) to use an additive correction factor of -11.3 for tests run on batch K cams and batch D tappets. This is shown as Option 1 (slide 30) on Kevin's presentation. This motion passed without objection (TEI, TMC waive). The TMC will issue an information letter and an ltms update accordingly.

There was further discussion regarding the ltms standard deviation for ACSW. Action was tabled until more data is available and reviewed by the panel.

The panel will continue to monitor the use of this hardware and the correction factors in case they need to be revised in the future.

Next Meeting:
The next meeting will be held at the call of the chair, once more data is available. The call ended at 12:30 pm.

Cummins ISB Industry Severity

April 2014

Kevin O'Malley
Statistician
The Lubrizol Corporation

Lubrizol

Data Used in Analysis

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Analysis includes chart="Y" data prior to 1/29/2015

+

Additional tests (since 1/29/2015):

TESTKEY	LTMSLAB	IND	LTMSAPP	ENGINE	ENHOURS	VAL	LTMSDATE	CHART	ENKIT	COM1	COM2	COM3	COM4	TAPBID	CRHBID	CAMBID
98396-ISB	B	831-2	3	46560892	4900	LC	20150129	N	ISB-749	SEVERE	ACSW	FAILED	INJ295HR	C	D	J
98397-ISB	B	831-2	3	46562869	5253	XC	20150206	N	ISB-765	ABORTED	EGR VLV	FAILURE	HIGH SOO	C	D	J
106237-ISB	B	831-2	3	46560892	5250	AC	20150226	Y	ISB-750					C	D	J
104605-ISB	A	831-2	3	46560643	7486	PC	20150227	N	ISB-824	NEW CAM	NEW TAP			D	D	K
105876-ISB	G	831-2	4	46561166	13355	XH	20150303	N	ISB-823	ENGINE	HW FAIL	OIL LOSS		D	K	J
105875-ISB	G	831-2	3	46560027	3457	PC	20150305	N	ISB-822	NEW CAM	NEW TAP			D	D	K
104606-ISB	A	831-2	4	49342610	3150	PC	20150307	Y	ISB-825	NEW CAM	NEW TAP			D	D	K
106978-ISB	G	831-2	1	46560896	7910	AG	20150308	N	ISB-826	NEW CAM	NEW TAP		HARDWARE	D	D	K
106854-ISB	B	831-2	3	46562869	5280	PC	20150313	N	ISB-821	NEW CAM	HARDWARE			D	D	K
106979-ISB	G	831-2	5	57339278	6950	PC	20150315	N	ISB-827	NEW CAM	NEW TAP			D	D	K

Included in graphs/analyses

Lubrizol

General Comments

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General comments before we get into the analysis:

1. It is NOT possible to simultaneously estimate any combination of Fuel Batch, Engine, Tappet Batch or Camshaft Batch effects
    1. The inability for models to separate these effects is a result of how the levels of these variables have been introduced in these data

2. Differences in fuel batches and engines may also influence oil and lab/stand differences

3. Thus, we must keep in mind that models and their resulting estimates (including correction factor calculations) may be influenced by these effects

4. More details regarding the relationship between these factors can be found in Appendix A

5. Prior presentation details have been moved to appendices:
    1. Appendix B: LTMS & Hardware Details
    2. Appendix C: Average Camshaft Wear graphs
    3. Appendix D: Average Tappet Weight Loss graphs

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Average Tappet Weight Loss (ATWLorig):

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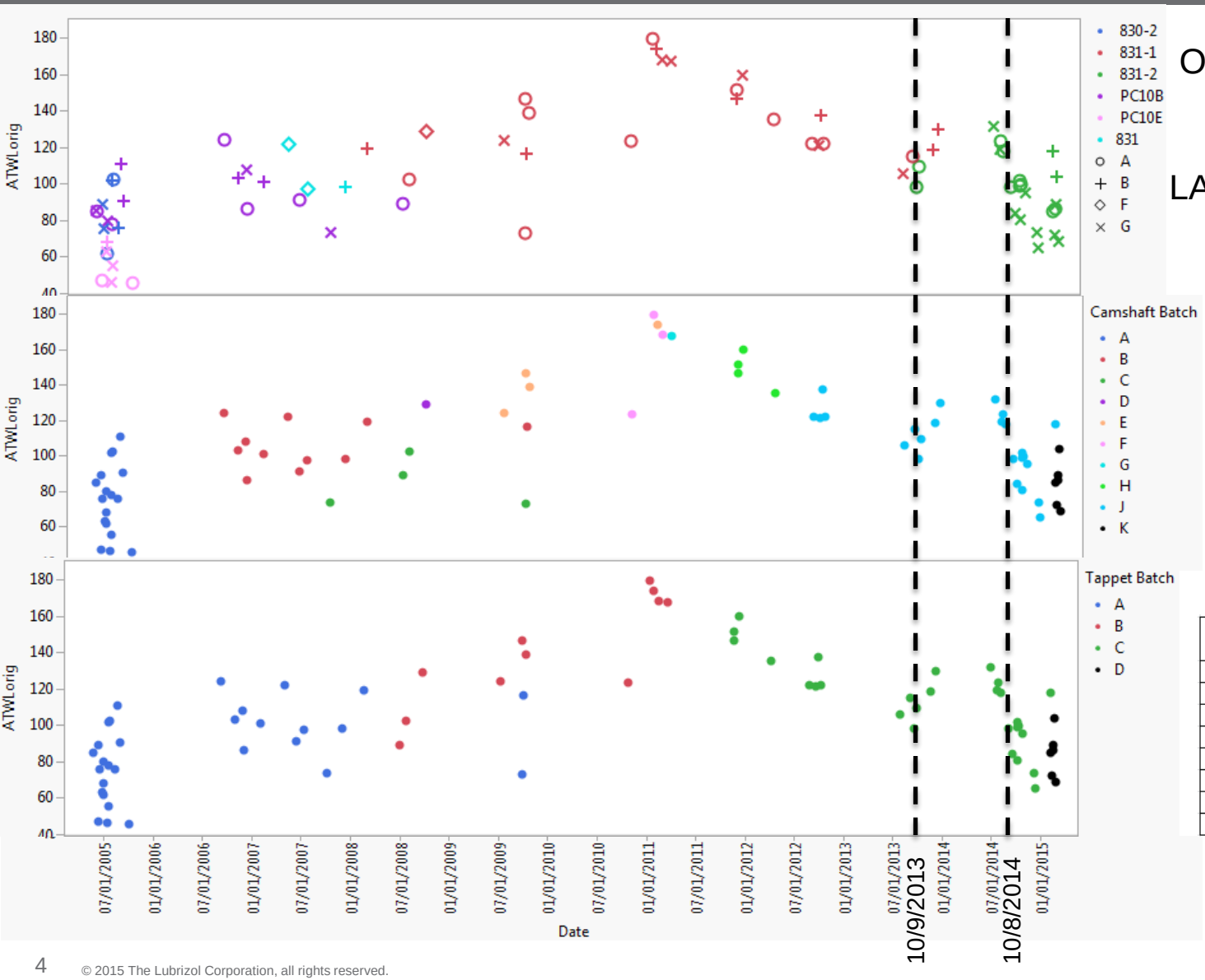

OIL

LAB

Camshaft Batch	IND	Number of tests	Mean(ATWLorig)
A	PC10B	6	88.1
B	831-1	2	117.5
B	PC10B	6	102.1
B	831	3	105.9
C	831-1	2	87.6
C	PC10B	2	81.5
D	831-1	1	129.2
E	831-1	4	145.7
F	831-1	3	157.1
G	831-1	1	167.2
H	831-1	4	148.1
J	831-1	8	121.2
J	831-2	16	100.9
K	831-2	6	84.1

Tappet Batch	IND	Number of tests	Mean(ATWLorig)
A	831-1	3	102.6
A	PC10B	13	93.4
A	831	3	105.9
B	831-1	10	145.3
B	PC10B	1	89.3
C	831-1	12	130.2
C	831-2	16	100.9
D	831-2	6	84.1

831 Target mean = 97.2

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ATWLorig
Model with Tappet Batch

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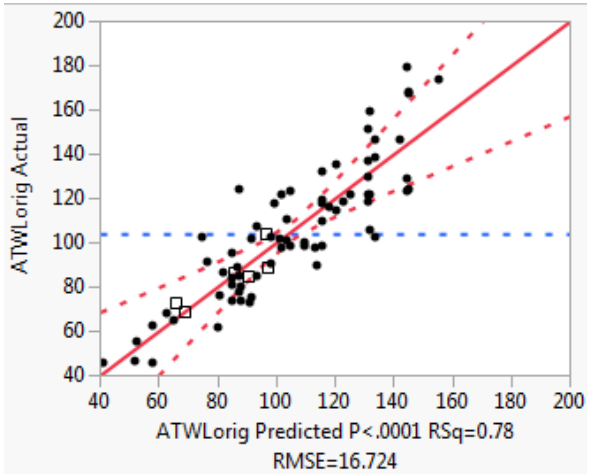

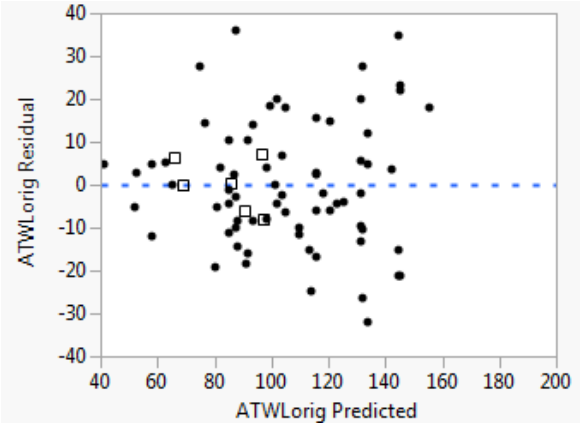

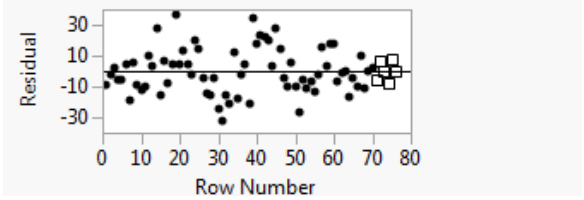

RSquare	0.776694
RSquare Adj	0.689852
Root Mean Square Error	16.72374
Mean of Response	103.8816
Observations (or Sum Wgts)	76

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	3	3	4259.6519	5.0768	0.0036*
LTMSAPP[LTMSLAB]	10	10	5536.5345	1.9796	0.0540
IND	5	5	8731.4348	6.2438	0.0001*
Tappet Batch	3	3	4891.2733	5.8295	0.0016*

Term	Estimate	Prob>|t|	VIF
Intercept	98.260195	<.0001*	
LTMSLAB[A]	-4.062095	0.4444	5.5179165
LTMSLAB[B]	14.199911	0.0084*	3.9691055
LTMSLAB[F]	4.9808169	0.6348	8.4110213
LTMSLAB[A]:LTMSAPP[1]	-6.765328	0.5435	1.3075203
LTMSLAB[A]:LTMSAPP[2]	9.2859192	0.1469	1.5204761
LTMSLAB[A]:LTMSAPP[3]	3.5951817	0.6191	1.2329944
LTMSLAB[A]:LTMSAPP[4]	-1.451692	0.8253	1.636367
LTMSLAB[B]:LTMSAPP[1]	1.959156	0.7405	1.7077695
LTMSLAB[B]:LTMSAPP[2]	6.9655162	0.3834	1.7853765
LTMSLAB[G]:LTMSAPP[1]	20.88216	0.0035*	2.0188069
LTMSLAB[G]:LTMSAPP[2]	26.524775	0.0052*	1.7179712
LTMSLAB[G]:LTMSAPP[3]	-10.08826	0.2245	1.3956079
LTMSLAB[G]:LTMSAPP[4]	-30.00754	0.0430*	1.4991477
IND[830-2]	-6.392438	0.3891	1.7212339
IND[831-1]	20.460352	0.0054*	3.8588398
IND[831-2]	4.6305711	0.6290	6.5754818
IND[PC10B]	0.7192055	0.8988	1.7461601
IND[PC10E]	-34.90914	<.0001*	1.8571485
Tappet Batch[A]	-16.59188	0.0590	7.6104934
Tappet Batch[B]	20.817469	0.0006*	1.9204923
Tappet Batch[C]	7.4354087	0.1044	2.0020346

Evidence that labs, oils, and tappet batches differ (possibly stands too)

Some correlation exists among model effects. This can be improved with the removal of 3 Lab F tests

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ATWLorig
Model with Tappet Batch

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Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	3	3	4259.6519	5.0768	0.0036*
LTMSAPP[LTMSLAB]	10	10	5536.5345	1.9796	0.0540
IND	5	5	8731.4348	6.2438	0.0001*
Tappet Batch	3	3	4891.2733	5.8295	0.0016*

Lab

Level		Least Sq Mean
B	A	112.46011
F	A B	103.24101
A	B	94.19810
G	B	83.14156

Lab B is higher on average than A and G
B > (A & G)

Tappet Batches

Level		Least Sq Mean
B	A	119.07766
C	A B	105.69560
D	B	86.59919
A	B	81.66832

Batch B is higher on average than D and A:
B > (A & D)

Lab Stands

Level		Least Sq Mean
[B]2	A B	119.42562
[B]1	A	114.41926
[G]2	A B	109.66634
[G]1	A B	104.02372
[B]3	A B	103.53543
[A]2	A B	103.48402
[F]1	A B	103.24101
[A]3	A B	97.79328
[A]4	A B	92.74641
[A]5	A B	89.53402
[A]1	A B	87.43277
[G]5	A B	75.83043
[G]3	B	73.05330
[G]4	A B	53.13402

Within lab, stands don't significantly differ

Lab G stands have the most spread

Oil

Level		Least Sq Mean
831-1	A	118.72055
831	A	113.75164
831-2	A B	102.89077
PC10B	A	98.97940
830-2	A B	91.86776
PC10E	B	63.35106

831 blends don't significantly differ

Levels not connected by same letter are significantly different.

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ATWLorig
Model with Tappet Batch

SUCCESS TOGETHER

Term	Estimate
Intercept	94.808546
IND[830-2]	-6.392438
IND[831-1]	20.460352
IND[831-2]	4.6305711
IND[PC10B]	0.7192055
IND[PC10E]	-34.90914
IND[831]	15.491448
Tappet Batch[A]	-16.59188
Tappet Batch[B]	20.817469
Tappet Batch[C]	7.4354087
Tappet Batch[D]	-11.661
LabStand[A1]	-7.375774
LabStand[A2]	8.6754738
LabStand[A3]	2.9847364
LabStand[A4]	-2.062137
LabStand[A5]	-5.274526
LabStand[B1]	19.610716
LabStand[B2]	24.617076
LabStand[B3]	8.7268875
LabStand[F1]	8.4324662
LabStand[G1]	9.2151767
LabStand[G2]	14.857791
LabStand[G3]	-21.75524
LabStand[G4]	-41.67453
LabStand[G5]	-18.97812

Using model we can estimate the mean of Tappet Batch D by averaging over labs/stands assuming the use of 831-2

Model predicted mean for Tappet D = 87.8 (6 test results)
Current oil target = 97.2 (14 test results)

This does not constitute a statistically significant difference

Note: Other models considered:

- 831 oil blends combined (no significant difference in blends)
- 3 Lab F results removed (to improve collinearity)
- 831 blends combined & Lab F tests removed

Model conclusions are similar;
Estimated Tappet D means range from 87.5 to 88.7

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ATWLorig
Other Models with Tappet Batch

SUCCESS TOGETHER

Combined 831 oil blends

Summary of Fit

RSquare	0.737872
RSquare Adj	0.655095
Root Mean Square Error	17.63595
Mean of Response	103.8816
Observations (or Sum Wgts)	76

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	93.386688	<.0001*	.
LTMSLAB[A]	-7.283847	0.1449	4.3349594
LTMSLAB[B]	15.722837	0.0018*	3.0604646
LTMSLAB[F]	11.69756	0.1666	4.8486826
LTMSLAB[A]:LTMSAPP[1]	-1.059992	0.9230	1.1441204
LTMSLAB[A]:LTMSAPP[2]	10.371986	0.1132	1.4275601
LTMSLAB[A]:LTMSAPP[3]	3.0934465	0.6816	1.2069803
LTMSLAB[A]:LTMSAPP[4]	-1.276489	0.8467	1.4843713
LTMSLAB[B]:LTMSAPP[1]	2.3671593	0.6981	1.6342111
LTMSLAB[B]:LTMSAPP[2]	6.9356158	0.3967	1.6856753
LTMSLAB[G]:LTMSAPP[1]	24.784669	0.0008*	1.901264
LTMSLAB[G]:LTMSAPP[2]	28.626915	0.0037*	1.6673009
LTMSLAB[G]:LTMSAPP[3]	-13.42339	0.1186	1.3358866
LTMSLAB[G]:LTMSAPP[4]	-34.67625	0.0250*	1.4594033
Tappet Batch[A]	-22.64855	<.0001*	2.1526545
Tappet Batch[B]	28.634125	<.0001*	1.3462455
Tappet Batch[C]	9.8893637	0.0140*	1.3521215
Ref Oil[830]	5.5424964	0.3331	1.2439806
Ref Oil[831]	16.736746	0.0007*	1.8007752

Removal of 3 Lab F results

Summary of Fit

RSquare	0.787392
RSquare Adj	0.705619
Root Mean Square Error	16.50225
Mean of Response	103.3726
Observations (or Sum Wgts)	73

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	94.340408	<.0001*	.
LTMSLAB[A]	-2.734006	0.4851	3.0821457
LTMSLAB[B]	16.480249	0.0002*	2.6406074
LTMSLAB[A]:LTMSAPP[1]	-6.461298	0.5566	1.307712
LTMSLAB[A]:LTMSAPP[2]	9.2884218	0.1417	1.512781
LTMSLAB[A]:LTMSAPP[3]	3.8150805	0.5931	1.2309954
LTMSLAB[A]:LTMSAPP[4]	-1.925948	0.7670	1.6317957
LTMSLAB[B]:LTMSAPP[1]	3.2364415	0.5835	1.7415895
LTMSLAB[B]:LTMSAPP[2]	6.6133771	0.4019	1.7864196
LTMSLAB[G]:LTMSAPP[1]	20.678126	0.0034*	2.0065982
LTMSLAB[G]:LTMSAPP[2]	27.06281	0.0040*	1.7180009
LTMSLAB[G]:LTMSAPP[3]	-10.19217	0.2140	1.3936192
LTMSLAB[G]:LTMSAPP[4]	-30.10402	0.0400*	1.4991766
IND[830-2]	-3.808866	0.6116	1.359182
IND[831-1]	23.234367	0.0022*	3.3790342
IND[831-2]	7.549098	0.4349	5.7309908
IND[PC10B]	3.5834097	0.5435	1.5990663
IND[PC10E]	-31.93534	0.0001*	1.4834682
Tappet Batch[A]	-17.43443	0.0454*	7.3705444
Tappet Batch[B]	22.172185	0.0003*	1.8628846
Tappet Batch[C]	7.1607558	0.1133	1.9862762

Combined 831 blends & Lab F tests removed

Summary of Fit

RSquare	0.749834
RSquare Adj	0.67251
Root Mean Square Error	17.40555
Mean of Response	103.3726
Observations (or Sum Wgts)	73

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	91.026832	<.0001*	.
LTMSLAB[A]	-3.610509	0.3765	3.0040137
LTMSLAB[B]	20.108889	<.0001*	2.3617359
LTMSLAB[A]:LTMSAPP[1]	-0.268152	0.9803	1.14635
LTMSLAB[A]:LTMSAPP[2]	10.376051	0.1086	1.4203354
LTMSLAB[A]:LTMSAPP[3]	3.3026202	0.6573	1.2049135
LTMSLAB[A]:LTMSAPP[4]	-2.101457	0.7480	1.4862737
LTMSLAB[B]:LTMSAPP[1]	2.2278375	0.7115	1.6335339
LTMSLAB[B]:LTMSAPP[2]	7.9866944	0.3251	1.6966395
LTMSLAB[G]:LTMSAPP[1]	24.459892	0.0008*	1.8906853
LTMSLAB[G]:LTMSAPP[2]	29.50011	0.0026*	1.6705454
LTMSLAB[G]:LTMSAPP[3]	-13.58726	0.1099	1.3340923
LTMSLAB[G]:LTMSAPP[4]	-34.82119	0.0228*	1.4594579
Tappet Batch[A]	-24.71145	<.0001*	2.229837
Tappet Batch[B]	30.840352	<.0001*	1.3743185
Tappet Batch[C]	9.7703724	0.0140*	1.339819
Ref Oil[830]	5.9855599	0.2907	1.2470463
Ref Oil[831]	15.722368	0.0013*	1.8227459

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ATWLorig
Other Models with Tappet Batch

SUCCESS TOGETHER

	Combined 831 oil blends	Removal of 3 Lab F results	Combined 831 blends & Lab F tests removed
Tappet Batch Differences			
Oil Differences			
Estimated Tappet D mean	88.7	87.5	87.8

Tappet Batch Differences

Level			Least Sq Mean
B	A		122.02081
C		B	103.27605
D		C	77.51175
A		C	70.73813

Level			Least Sq Mean
B	A		116.51259
C	A	B	101.50116
D		B	82.44190
A		B	76.90598

Level			Least Sq Mean
B	A		121.86718
C		B	100.79720
D		C	75.12756
A		C	66.31538

Oil Differences

Level			Least Sq Mean
831	A		110.12343
830	A		98.92918
PC10E		B	71.10745

Level			Least Sq Mean
831-1	A		117.57478
831-2	A	B	101.88951
PC10B	A		97.92382
831	A	B	95.71774
830-2	A	B	90.53154
PC10E		B	62.40507

Level			Least Sq Mean
831	A		106.74920
830	A		97.01239
PC10E		B	69.31890

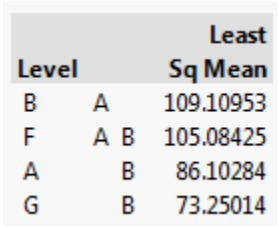
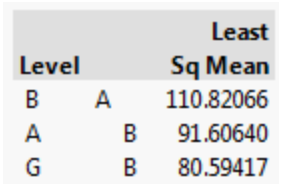
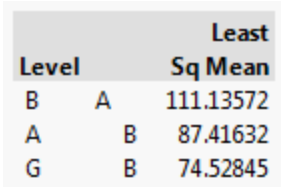
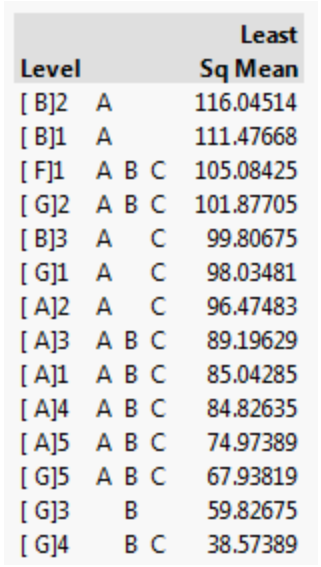
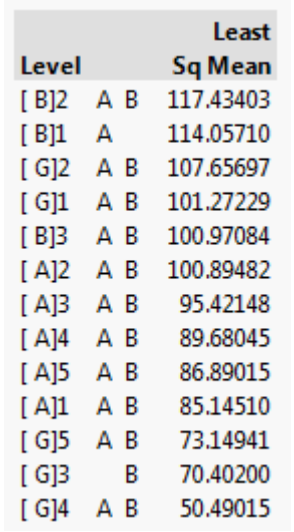
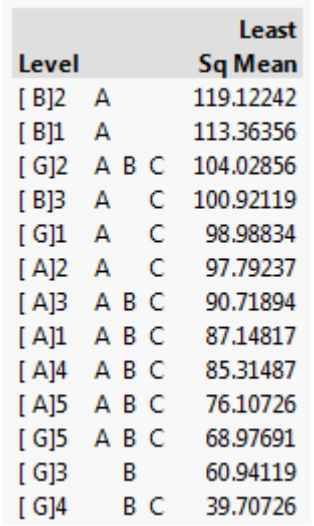
Levels not connected by same letter are significantly different.

Estimated means do not significantly differ from current oil target
Current 831 target mean = 97.2

Lubrizol

ATWLorig
Other Models with Tappet Batch

SUCCESS TOGETHER

	Combined 831 oil blends	Removal of 3 Lab F results	Combined 831 blends & Lab F tests removed
Labs Differences			
Stand Differences			

Level		Least Sq Mean
B	A	109.10953
F	A B	105.08425
A	B	86.10284
G	B	73.25014

Level		Least Sq Mean
B	A	110.82066
A	B	91.60640
G	B	80.59417

Level		Least Sq Mean
B	A	111.13572
A	B	87.41632
G	B	74.52845

Level		Least Sq Mean
[B]2	A	116.04514
[B]1	A	111.47668
[F]1	A B C	105.08425
[G]2	A B C	101.87705
[B]3	A C	99.80675
[G]1	A C	98.03481
[A]2	A C	96.47483
[A]3	A B C	89.19629
[A]1	A B C	85.04285
[A]4	A B C	84.82635
[A]5	A B C	74.97389
[G]5	A B C	67.93819
[G]3	B	59.82675
[G]4	B C	38.57389

Level		Least Sq Mean
[B]2	A B	117.43403
[B]1	A	114.05710
[G]2	A B	107.65697
[G]1	A B	101.27229
[B]3	A B	100.97084
[A]2	A B	100.89482
[A]3	A B	95.42148
[A]4	A B	89.68045
[A]5	A B	86.89015
[A]1	A B	85.14510
[G]5	A B	73.14941
[G]3	B	70.40200
[G]4	A B	50.49015

Level		Least Sq Mean
[B]2	A	119.12242
[B]1	A	113.36356
[G]2	A B C	104.02856
[B]3	A C	100.92119
[G]1	A C	98.98834
[A]2	A C	97.79237
[A]3	A B C	90.71894
[A]1	A B C	87.14817
[A]4	A B C	85.31487
[A]5	A B C	76.10726
[G]5	A B C	68.97691
[G]3	B	60.94119
[G]4	B C	39.70726

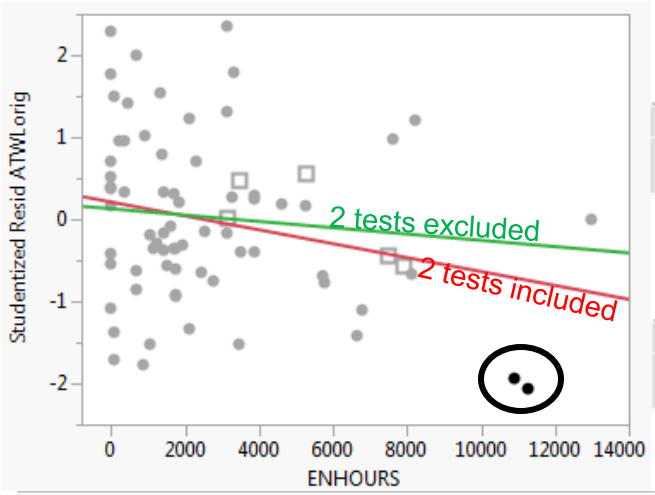
Levels not connected by same letter are significantly different.

Lubrizol

ATWLorig
Model with Tappet Batch

SUCCESS TOGETHER

Engine hours effect heavily influenced by 2 test results; could be hardware related

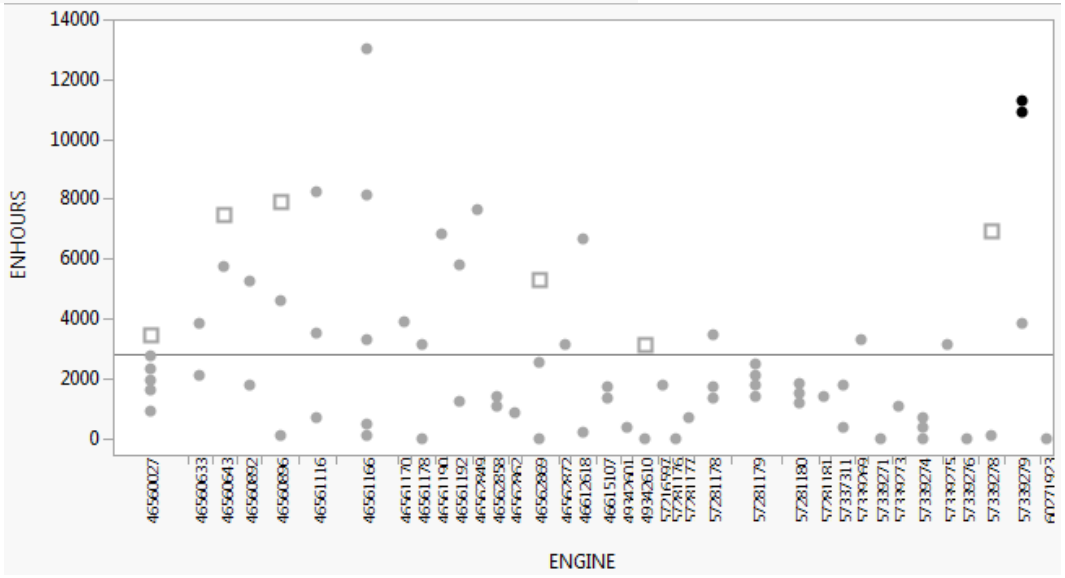


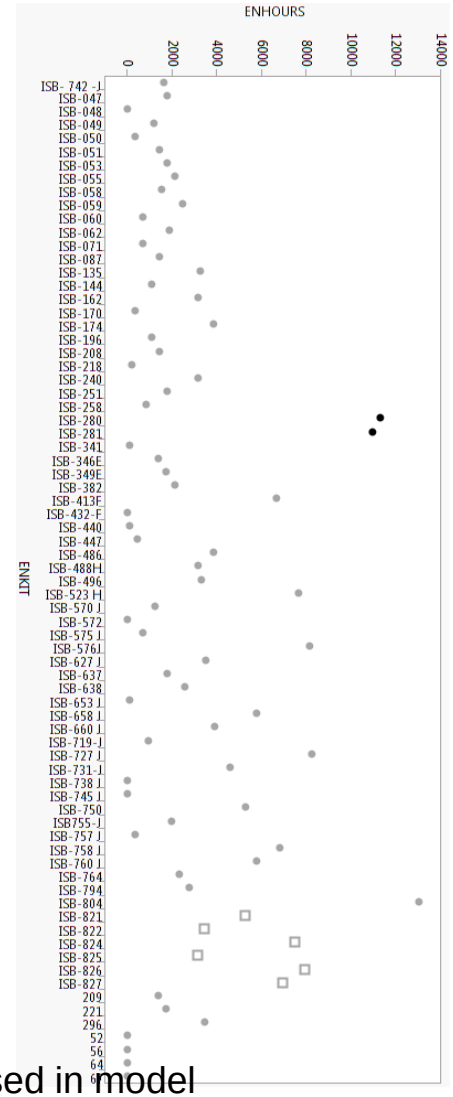
With 2 Tests Included

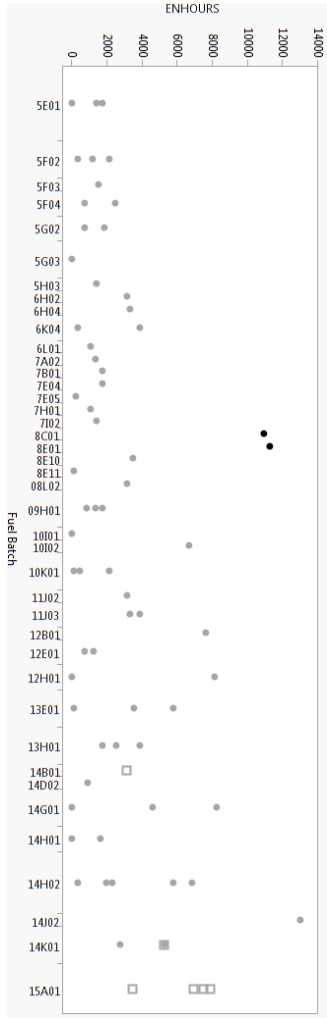
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.219657	0.158544	1.39	0.1702
ENHOURS	-8.466e-5	3.966e-5	-2.13	0.0362*

With 2 Tests Excluded

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1384675	0.160063	0.87	0.3899
ENHOURS	-3.84e-5	4.438e-5	-0.87	0.3899







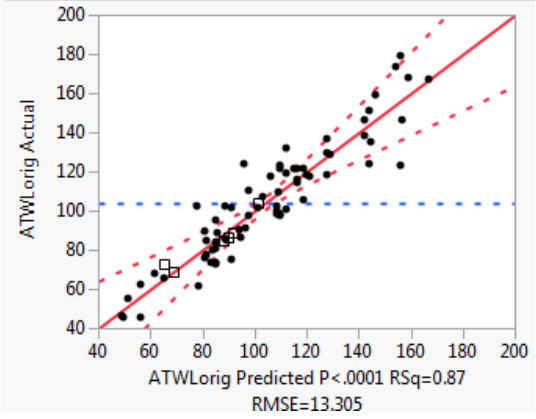
NOTE: No significant ENHOURS effect when Camshaft batch used in model

Lubrizol

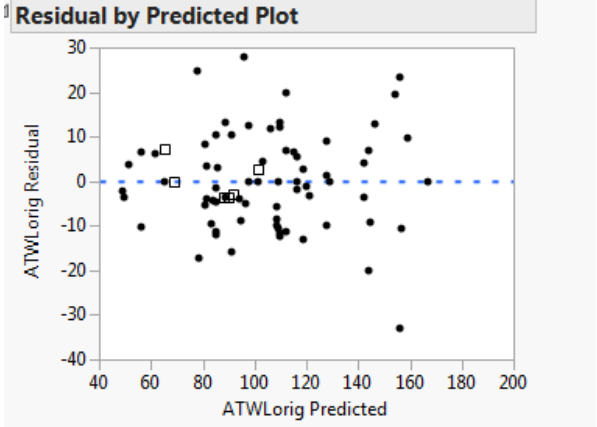
ATWLorig
Model with Camshaft Batch

SUCCESS TOGETHER

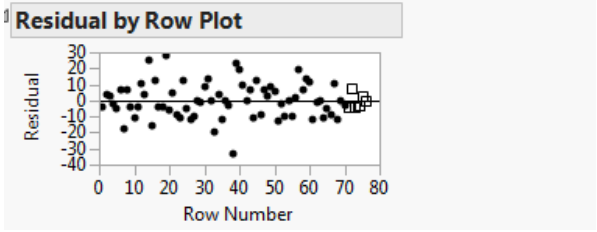
Actual by Predicted Plot



Residual by Predicted Plot



Residual by Row Plot



Summary of Fit

RSquare	0.874369
RSquare Adj	0.803702
Root Mean Square Error	13.30475
Mean of Response	103.8816
Observations (or Sum Wgts)	76

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	3	3	4050.761	7.6278	0.0003*
LTMSAPP[LTMSLAB]	10	10	3729.862	2.1071	0.0422*
IND	5	5	4048.928	4.5746	0.0017*
Camshaft Batch	9	9	11497.401	7.2168	<.0001*

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	111.54198	<.0001*	.
LTMSLAB[A]	-7.356092	0.1904	9.6210005
LTMSLAB[B]	8.6558442	0.0987	6.1425712
LTMSLAB[F]	19.474737	0.1372	20.289166
LTMSLAB[A]:LTMSAPP[1]	-1.154393	0.8974	1.3378904
LTMSLAB[A]:LTMSAPP[2]	2.3942497	0.6598	1.7635036
LTMSLAB[A]:LTMSAPP[3]	1.3822145	0.8148	1.2984135
LTMSLAB[A]:LTMSAPP[4]	2.8448504	0.5787	1.5628033
LTMSLAB[B]:LTMSAPP[1]	-0.981108	0.8428	1.885911
LTMSLAB[B]:LTMSAPP[2]	2.8045484	0.6668	1.8815629
LTMSLAB[G]:LTMSAPP[1]	18.367712	0.0016*	2.0697919
LTMSLAB[G]:LTMSAPP[2]	23.044722	0.0030*	1.7736994
LTMSLAB[G]:LTMSAPP[3]	-8.309668	0.2103	1.4008416
LTMSLAB[G]:LTMSAPP[4]	-28.44852	0.0172*	1.5009844
IND[830-2]	3.2593052	0.6636	2.783442
IND[831-1]	13.935733	0.0436*	5.526606
IND[831-2]	7.1633333	0.4188	8.8247172
IND[PC10B]	6.20969	0.2136	2.1129634
IND[PC10E]	-26.23372	0.0012*	2.8913892
Camshaft Batch[A]	-31.19749	0.0019*	11.311828
Camshaft Batch[B]	-16.88238	0.0370*	5.8342805
Camshaft Batch[C]	-32.07976	0.0002*	3.6634272
Camshaft Batch[D]	-15.75245	0.4272	14.583029
Camshaft Batch[E]	21.160914	0.0055*	2.980854
Camshaft Batch[F]	35.732436	<.0001*	3.5157481
Camshaft Batch[G]	44.129059	0.0014*	6.3428421
Camshaft Batch[H]	23.648564	0.0017*	2.854729
Camshaft Batch[J]	-4.282304	0.4742	5.1233344

Evidence that labs, oils, stands, and camshaft batches differ

Undesired level of correlation exists among model effects.

This can be improved with the removal of 3 Lab F tests

Lubrizol

ATWLorig
Model with Camshaft Batch

SUCCESS TOGETHER

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
LTMSLAB	3	3	4050.761	7.6278	0.0003*
LTMSAPP[LTMSLAB]	10	10	3729.862	2.1071	0.0422*
IND	5	5	4048.928	4.5746	0.0017*
Camshaft Batch	9	9	11497.401	7.2168	<.0001*

Lab

Level		Least Sq Mean
F	A B	131.01672
B	A	120.19783
A	B	104.18589
G	B	90.76750

Lab B is higher on average than A and G
B > (A & G)

Oil

Level		Least Sq Mean
831-1	A	125.47772
831-2	A B	118.70532
PC10B	A	117.75167
830-2	A	114.80129
831	A B	107.20764
PC10E	B	85.30827

831 blends don't significantly differ

Lab Stands

Level		Least Sq Mean
[F]1	A B C	131.01672
[B]2	A B	123.00238
[B]1	A	119.21672
[B]3	A	118.37439
[G]2	A B C	113.81222
[G]1	A B C	109.13521
[A]4	A B C	107.03074
[A]2	A B C	106.58014
[A]3	A B C	105.56811
[A]1	A B C	103.03150
[A]5	A B C	98.71897
[G]5	A B C	86.11325
[G]3	B C	82.45783
[G]4	C	62.31897

Within lab, stands don't significantly differ

Lab G stands have the most spread

Camshaft Batches

Level		Least Sq Mean
G	A B	155.67104
F	A	147.27442
H	A B	135.19055
E	A B	132.70290
J	B C	107.25968
D	A B C	95.78953
B	C	94.65961
K	C	87.06540
A	C	80.34449
C	C	79.46222

Batch differences exist

Levels not connected by same letter are significantly different.

Lubrizol

ATWLorig
Model with Camshaft Batch

SUCCESS TOGETHER

Term	Estimate
Intercept	104.74122
IND[830-2]	3.2593052
IND[831-1]	13.935733
IND[831-2]	7.1633333
IND[PC10B]	6.20969
IND[PC10E]	-26.23372
Camshaft Batch[A]	-31.19749
Camshaft Batch[B]	-16.88238
Camshaft Batch[C]	-32.07976
Camshaft Batch[D]	-15.75245
Camshaft Batch[E]	21.160914
Camshaft Batch[F]	35.732436
Camshaft Batch[G]	44.129059
Camshaft Batch[H]	23.648564
Camshaft Batch[J]	-4.282304
LabStand[A1]	-1.709726
LabStand[A2]	1.8389171
LabStand[A3]	0.826882
LabStand[A4]	2.2895178
LabStand[A5]	-6.022254
LabStand[B1]	14.475496
LabStand[B2]	18.261152
LabStand[B3]	13.633163
LabStand[F1]	26.275496
LabStand[G1]	4.3939828
LabStand[G2]	9.0709932
LabStand[G3]	-22.2834
LabStand[G4]	-42.42225

Using model we can estimate the mean of Camshaft Batch K by averaging over lab/stands assuming the use of 831-2

Model predicted mean for Camshaft K = 87.4 (6 test results)
Current oil target = 97.2 (14 test results)

This does not constitute a statistically significant difference

Note: Other models were considered:

- 831 oil blends combined (no significant difference in blends)
- 3 Lab F results removed (to improve collinearity)
- 831 blends combined & Lab F tests removed

Model conclusions are similar;
Estimated Cam K means range from 85.3 to 87.4

Lubrizol

ATWLorig
Other Models with Camshaft Batch

SUCCESS TOGETHER

Combined 831 oil blends

Summary of Fit

RSquare	0.867579
RSquare Adj	0.805263
Root Mean Square Error	13.25175
Mean of Response	103.8816
Observations (or Sum Wgts)	76

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	109.39555	<.0001*	.
LTMSLAB[A]	-5.110663	0.2413	5.8757923
LTMSLAB[B]	12.721743	0.0018*	3.5070939
LTMSLAB[F]	11.425516	0.1642	8.0730945
LTMSLAB[A]:LTMSAPP[1]	0.0178046	0.9984	1.2561762
LTMSLAB[A]:LTMSAPP[2]	2.7362116	0.6079	1.7089799
LTMSLAB[A]:LTMSAPP[3]	1.6217482	0.7793	1.2593051
LTMSLAB[A]:LTMSAPP[4]	3.1453191	0.5318	1.5190162
LTMSLAB[B]:LTMSAPP[1]	-2.818064	0.5513	1.7336862
LTMSLAB[B]:LTMSAPP[2]	3.9685699	0.5264	1.7517683
LTMSLAB[G]:LTMSAPP[1]	19.24426	0.0008*	1.9849811
LTMSLAB[G]:LTMSAPP[2]	23.903287	0.0019*	1.7504785
LTMSLAB[G]:LTMSAPP[3]	-9.372167	0.1504	1.3583628
LTMSLAB[G]:LTMSAPP[4]	-29.99515	0.0110*	1.4708937
Camshaft Batch[A]	-37.29237	<.0001*	4.4910716
Camshaft Batch[B]	-22.49798	<.0001*	2.4430058
Camshaft Batch[C]	-34.11849	<.0001*	2.9935427
Camshaft Batch[D]	-3.097979	0.8411	8.9828511
Camshaft Batch[E]	23.282373	0.0012*	2.6267872
Camshaft Batch[F]	37.741283	<.0001*	3.1051379
Camshaft Batch[G]	46.119872	0.0006*	6.0308747
Camshaft Batch[H]	25.75965	0.0003*	2.4989512
Camshaft Batch[J]	-6.640716	0.1280	2.700391
Ref Oil[830]	9.0437601	0.0517	1.4075782
Ref Oil[831]	11.47691	0.0154*	3.0697327

Removal of 3 Lab F results

Summary of Fit

RSquare	0.8769
RSquare Adj	0.811422
Root Mean Square Error	13.20791
Mean of Response	103.3726
Observations (or Sum Wgts)	73

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	106.80068	<.0001*	.
LTMSLAB[A]	-0.864513	0.7898	3.3098892
LTMSLAB[B]	15.147423	<.0001*	2.8896104
LTMSLAB[A]:LTMSAPP[1]	-1.154393	0.8967	1.3376481
LTMSLAB[A]:LTMSAPP[2]	2.3942497	0.6575	1.7545784
LTMSLAB[A]:LTMSAPP[3]	1.3822145	0.8135	1.2957824
LTMSLAB[A]:LTMSAPP[4]	2.8448504	0.5760	1.5548939
LTMSLAB[B]:LTMSAPP[1]	-0.981108	0.8417	1.8847278
LTMSLAB[B]:LTMSAPP[2]	2.8045484	0.6645	1.8810508
LTMSLAB[G]:LTMSAPP[1]	18.367712	0.0015*	2.0564782
LTMSLAB[G]:LTMSAPP[2]	23.044722	0.0028*	1.7710487
LTMSLAB[G]:LTMSAPP[3]	-8.309668	0.2072	1.3987482
LTMSLAB[G]:LTMSAPP[4]	-28.44852	0.0165*	1.5009844
IND[830-2]	3.2593052	0.6614	2.0864377
IND[831-1]	13.935733	0.0423*	4.5357846
IND[831-2]	7.1633333	0.4155	7.3904954
IND[PC10B]	6.20969	0.2105	1.7395495
IND[PC10E]	-26.23372	0.0011*	2.1673536
Camshaft Batch[A]	-32.94776	0.0008*	10.6176
Camshaft Batch[B]	-18.63265	0.0174*	4.8743163
Camshaft Batch[C]	-33.83003	<.0001*	3.326259
Camshaft Batch[E]	19.410641	0.0082*	2.816124
Camshaft Batch[F]	33.982164	0.0001*	3.2942124
Camshaft Batch[G]	42.378787	0.0015*	6.0501514
Camshaft Batch[H]	21.898291	0.0026*	2.695675
Camshaft Batch[J]	-6.032577	0.2783	4.4317095

Combined 831 blends & Lab F tests removed

Summary of Fit

RSquare	0.870005
RSquare Adj	0.812807
Root Mean Square Error	13.15931
Mean of Response	103.3726
Observations (or Sum Wgts)	73

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	105.93127	<.0001*	.
LTMSLAB[A]	-1.302158	0.6834	3.2298485
LTMSLAB[B]	16.530248	<.0001*	2.6006992
LTMSLAB[A]:LTMSAPP[1]	0.0178046	0.9983	1.2559488
LTMSLAB[A]:LTMSAPP[2]	2.7362116	0.6054	1.7003306
LTMSLAB[A]:LTMSAPP[3]	1.6217482	0.7779	1.2567532
LTMSLAB[A]:LTMSAPP[4]	3.1453191	0.5290	1.5113283
LTMSLAB[B]:LTMSAPP[1]	-2.818064	0.5486	1.7325985
LTMSLAB[B]:LTMSAPP[2]	3.9685699	0.5236	1.7512915
LTMSLAB[G]:LTMSAPP[1]	19.24426	0.0007*	1.9722129
LTMSLAB[G]:LTMSAPP[2]	23.903287	0.0018*	1.7478626
LTMSLAB[G]:LTMSAPP[3]	-9.372167	0.1477	1.3563329
LTMSLAB[G]:LTMSAPP[4]	-29.99515	0.0105*	1.4708937
Camshaft Batch[A]	-37.63659	<.0001*	4.2399402
Camshaft Batch[B]	-22.8422	<.0001*	2.4159374
Camshaft Batch[C]	-34.46271	<.0001*	2.7735183
Camshaft Batch[E]	22.938153	0.0009*	2.4478435
Camshaft Batch[F]	37.397063	<.0001*	2.9138457
Camshaft Batch[G]	45.775652	0.0005*	5.7519093
Camshaft Batch[H]	25.41543	0.0002*	2.3262195
Camshaft Batch[J]	-6.984936	0.0806	2.2651228
Ref Oil[830]	9.0437601	0.0502	1.4075782
Ref Oil[831]	11.47691	0.0148*	3.0488362

Lubrizol

ATWLorig
Other Models with Camshaft Batch

SUCCESS TOGETHER

	Combined 831 oil blends	Removal of 3 Lab F results	Combined 831 blends & Lab F tests removed
Camshaft Batch Differences			

Level				Least Sq Mean
G	A			155.51542
F	A			147.13684
H	A			135.15520
E	A			132.67793
D	A	B	C	106.29757
J		B		102.75484
B		B	C	86.89757
K			C	80.13991
C			C	75.27706
A			C	72.10318

Level				Least Sq Mean
G	A			149.17946
F	A			140.78284
H	A	B		128.69897
E	A	B		126.21132
J		B	C	100.76810
B			C	88.16803
K			C	80.57382
A			C	73.85291
C			C	72.97065

Level				Least Sq Mean
G	A			151.70692
F	A			143.32833
H	A			131.34670
E	A			128.86942
J		B		98.94633
B		B	C	83.08907
K			C	76.33141
C			C	71.46856
A			C	68.29468

Oil Differences

Level				Least Sq Mean
831	A			120.87246
830	A			118.43931
PC10E		B		88.87488

Level				Least Sq Mean
831-1	A			120.73641
831-2	A	B		113.96401
PC10B	A			113.01037
830-2	A			110.05998
831		A	B	102.46633
PC10E			B	80.56696

Level				Least Sq Mean
831	A			117.40818
830	A			114.97503
PC10E		B		85.41060

Estimated Camshaft K mean: 86.5 | 85.4 | 85.3

Estimated means do not significantly differ from current oil target
Current 831 Target mean = 97.2

Levels not connected by same letter are significantly different.

Lubrizol

ATWLorig
Other Models with Camshaft Batch

SUCCESS TOGETHER

	Combined 831 oil blends	Removal of 3 Lab F results	Combined 831 blends & Lab F tests removed

Labs Differences

Level		Least Sq Mean
B	A	122.11730
F	A B	120.82107
A	B	104.28489
G	B	90.35896

Level		Least Sq Mean
B	A	121.94810
A	B	105.93616
G	B	92.51777

Level		Least Sq Mean
B	A	122.46152
A	B	104.62911
G	C	90.70318

Stand Differences

Level		Least Sq Mean
[B]2	A	126.08587
[B]3	A	120.96679
[F]1	A B C	120.82107
[B]1	A	119.29923
[G]2	A B C	114.26224
[G]1	A C	109.60322
[A]4	A B C	107.43021
[A]2	A B C	107.02110
[A]3	A B C	105.90664
[A]1	A B C	104.30269
[A]5	A B C	96.76381
[G]5	A B C	86.57873
[G]3	B	80.98679
[G]4	B C	60.36381

Level		Least Sq Mean
[B]2	A	124.75265
[B]1	A	120.96699
[B]3	A	120.12466
[G]2	A B	115.56249
[G]1	A B	110.88548
[A]4	A B	108.78102
[A]2	A B	108.33041
[A]3	A B	107.31838
[A]1	A B	104.78177
[A]5	A B	100.46924
[G]5	A B	87.86353
[G]3	B	84.20810
[G]4	B	64.06924

Level		Least Sq Mean
[B]2	A	126.43009
[B]3	A	121.31101
[B]1	A	119.64345
[G]2	A B	114.60646
[G]1	A	109.94744
[A]4	A B C	107.77443
[A]2	A B C	107.36532
[A]3	A B C	106.25086
[A]1	A B C	104.64691
[A]5	A B C	97.10803
[G]5	A B C	86.92295
[G]3	B C	81.33101
[G]4	C	60.70803

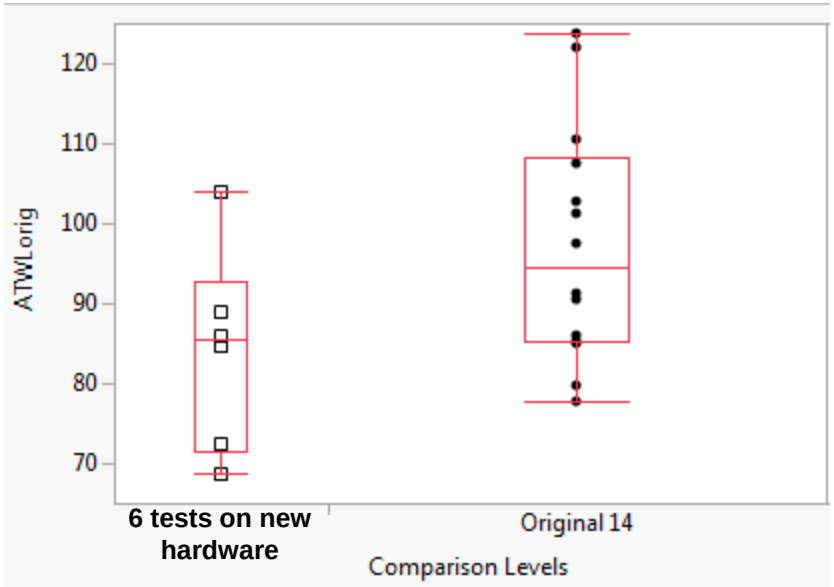
Levels not connected by same letter are significantly different.

Lubrizol

ATWLorig
Non-Model based comparison

SUCCESS TOGETHER

Comparisons between 6 tests with latest hardware and the original 14 tests used to generate current targets



Means and Std Deviations

Level	Number	Mean	Std Dev
6 tests on new hardware	6	84.1333	12.5731
Original 14	14	97.1857	14.7668

There is no significant difference between the mean of the latest 6 tests on the new hardware and the original target

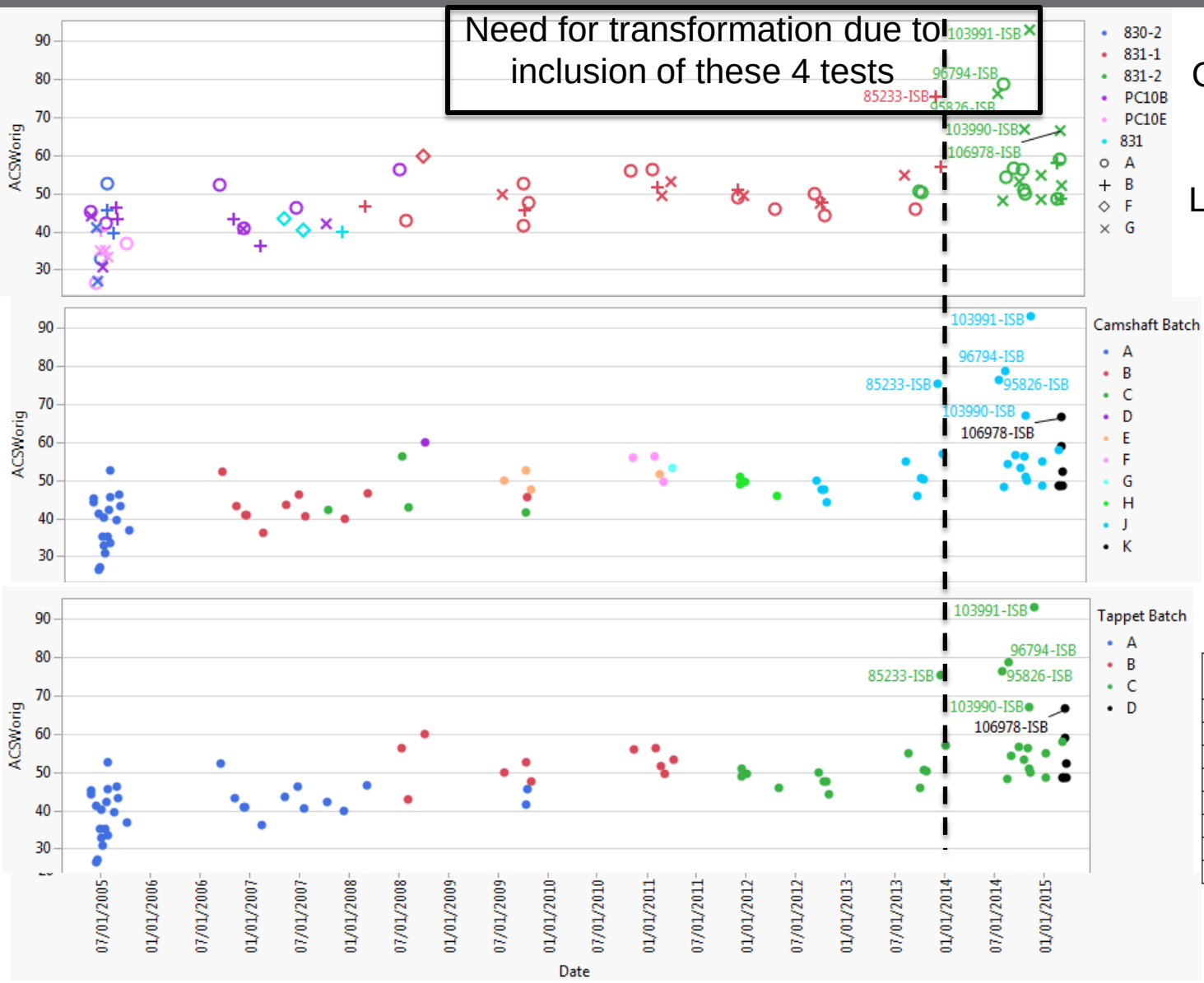
There is no significant difference between the variability observed in the 6 tests on the new hardware and the original 14 tests used to calculate the current oil target

Lubrizol

Average Camshaft Wear

SUCCESS TOGETHER

Need for transformation due to inclusion of these 4 tests



OIL

LAB

Camshaft Batch	IND	Number of tests	Mean(ACSWorig)
A	PC10B	6	41.9
B	831-1	2	45.9
B	PC10B	6	43.2
B	831	3	41.3
C	831-1	2	42.2
C	PC10B	2	49.2
D	831-1	1	59.8
E	831-1	4	50.4
F	831-1	3	53.8
G	831-1	1	53.1
H	831-1	4	48.8
J	831-1	8	52.9
J	831-2	16	59.2
K	831-2	6	53.8

Tappet Batch	IND	Number of tests	Mean(ACSWorig)
A	831-1	3	44.4
A	PC10B	13	42.5
A	831	3	41.3
B	831-1	10	51.9
B	PC10B	1	56.2
C	831-1	12	51.5
C	831-2	16	59.2
D	831-2	6	53.8

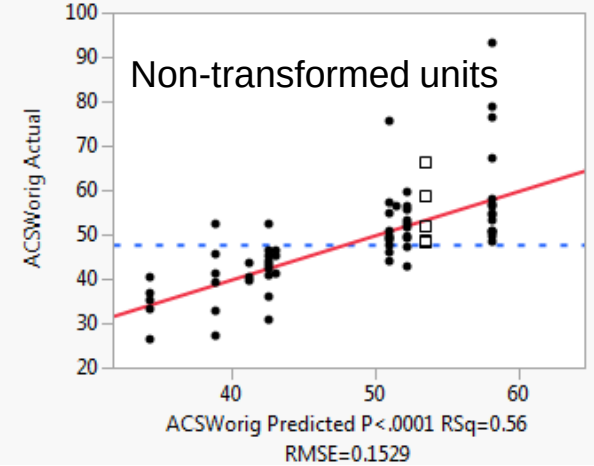
831 Target mean = 42.5

Lubrizol

ACSWorig
Model with Tappet Batch

SUCCESS TOGETHER

All 76 tests utilized; natural logarithm transformation applied: ln(ACSWorig)

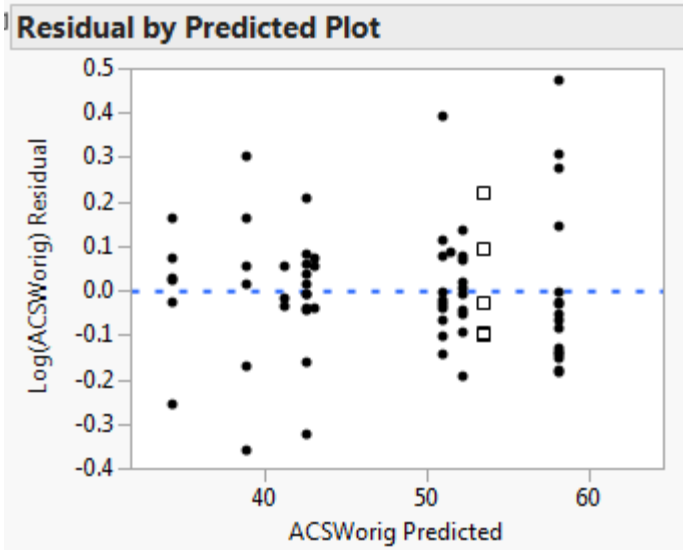


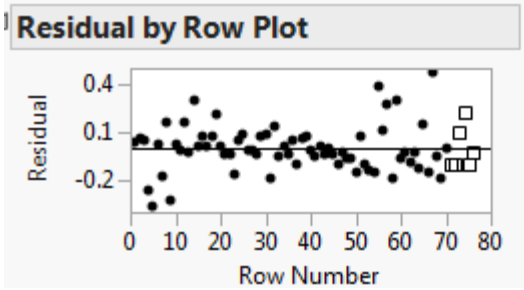
Summary of Fit

RSquare	0.56068
RSquare Adj	0.508223
Root Mean Square Error	0.152948
Mean of Response	3.866693
Observations (or Sum Wgts)	76

Effect Test

Source	Prob > F
IND	0.0228*
Tappet Batch	0.1018





Lubrizol

ACSWorig
Model with Tappet Batch

All 76 tests utilized; natural logarithm transformation applied: ln(ACSWorig)

Effect Test

Source	Prob > F
IND	0.0228*
Tappet Batch	0.1018

Oils differ (831-2 > PC10E)

Tappet batches tend to be different

Non-transformed units shown;
Comparisons made in transformed units

Level			Least Sq Mean
831-2	A		54.809980
831-1	A	B	48.132427
PC10B	A	B	47.516672
831	A	B	46.091516
830-2	A	B	43.456491
PC10E		B	38.348302

Expanded Estimates Transformed units

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.8313347	0.044384	86.32	<.0001*
IND[830-2]	-0.059575	0.062401	-0.95	0.3432
IND[831-1]	0.0426214	0.056461	0.75	0.4530
IND[831-2]	0.1725376	0.073907	2.33	0.0226*
IND[PC10B]	0.0297459	0.046567	0.64	0.5251
IND[PC10E]	-0.184624	0.062401	-2.96	0.0043*
IND[831]	-0.000706	0.08058	-0.01	0.9930
Tappet Batch[A]	-0.111319	0.064679	-1.72	0.0898
Tappet Batch[B]	0.0796552	0.0473	1.68	0.0968
Tappet Batch[C]	0.0573368	0.03746	1.53	0.1306
Tappet Batch[D]	-0.025673	0.063904	-0.40	0.6892

Using the model we can estimate the mean of Tappet D assuming the use of 831-2

Model predicted mean for Tappet D = 53.4 (3.9782 in ln units)
Current oil target = 42.5

The estimated mean for Tappet D is significantly different than the current oil target

ACSWorig
Models with Tappet Batch

SUCCESS TOGETHER

	All data; Oil blends included	All data; Oil blends combined	4 tests removed; Oil blends included	4 tests removed; Oil blends combined

Model Summary of Fit

Summary of Fit				
RSquare	0.56068	0.527319	0.608524	0.582073
RSquare Adj	0.508223	0.493556	0.558813	0.550412
Root Mean Square Error	0.152948	0.155212	5.386875	5.437922
Mean of Response	3.866693	3.866693	47.15278	47.15278
Observations (or Sum Wgts)	76	76	72	72

Overall Tests

Source	Prob > F	Source	Prob > F	Source	Prob > F	Source	Prob > F
IND	0.0228*	Tappet Batch	<.0001*	IND	0.0198*	Tappet Batch	<.0001*
Tappet Batch	0.1018	Ref Oil	0.0163*	Tappet Batch	0.0283*	Ref Oil	0.0090*

Model

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	3.8313347	<.0001*	.
IND[830-2]	-0.059575	0.3432	1.4784045
IND[831-1]	0.0426214	0.4530	2.9478306
IND[831-2]	0.1725376	0.0226*	4.7283067
IND[PC10B]	0.0297459	0.5251	1.4282767
IND[PC10E]	-0.184624	0.0043*	1.4784045
Tappet Batch[A]	-0.111319	0.0898	5.1461253
Tappet Batch[B]	0.0796552	0.0968	1.5944215
Tappet Batch[C]	0.0573368	0.1306	1.6575209

Parameter Estimates

Term	Estimate	Prob>|t|	VIF
Intercept	3.8214092	<.0001*	.
Tappet Batch[A]	-0.173803	<.0001*	1.3794183
Tappet Batch[B]	0.0316515	0.4337	1.118205
Tappet Batch[C]	0.0847414	0.0076*	1.0908186
Ref Oil[830]	0.0128349	0.7929	1.1812865
Ref Oil[831]	0.0993801	0.0112*	1.5552478

Term	Estimate	Prob>|t|	VIF
Intercept	46.965469	<.0001*	.
IND[830-2]	-1.725776	0.4361	1.4827327
IND[831-1]	1.5393061	0.4428	2.8574845
IND[831-2]	5.9672781	0.0300*	4.5884908
IND[PC10B]	1.3540769	0.4137	1.429439
IND[PC10E]	-6.909109	0.0026*	1.4827327
Tappet Batch[A]	-5.473026	0.0202*	5.1435857
Tappet Batch[B]	3.7757002	0.0290*	1.6392246
Tappet Batch[C]	0.8134067	0.5489	1.6009372

Term	Estimate	rob>|t|	VIF
Intercept	46.471611	<.0001*	.
Tappet Batch[A]	-7.479506	<.0001*	1.3680533
Tappet Batch[B]	2.157815	0.1313	1.1231744
Tappet Batch[C]	1.6108453	0.1570	1.0920492
Ref Oil[830]	0.7745614	0.6513	1.1812865
Ref Oil[831]	3.6342105	0.0084*	1.5409357

Oil & Tappets

Level		Least Sq Mean
831-2	A	54.809980
831-1	A B	48.132427
PC10B	A B	47.516672
831	A B	46.091516
830-2	A B	43.456491
PC10E	B	38.348302

Level		Least Sq Mean
B	A	49.948372
C	A	48.845951
D	A	44.954989
A	A	41.265046

Level		Least Sq Mean
831	A	50.440243
830	A B	46.258448
PC10E	B	40.820897

Level		Least Sq Mean
C	A	49.707238
D	A	48.367068
B	A	47.137113
A	B	38.382681

Level		Least Sq Mean
831-2	A	52.932747
831-1	A B	48.504775
PC10B	A	48.319546
831	A B	46.739693
830-2	A B	45.239693
PC10E	B	40.056360

Level		Least Sq Mean
B	A	50.741169
D	A B	47.849389
C	A B	47.778876
A	B	41.492443

Level		Least Sq Mean
D	A	50.182456
B	A	48.629426
C	A	48.082456
A	B	38.992105

Level		Least Sq Mean
831	A	50.105821
830	A B	47.246172
PC10E	B	42.062839

Estimated Tappet D mean (transformed units)

53.4 (3.9782) | 53.4 (3.9782) | 53.8 | 53.8

Estimated means differ from current oil target in all models

Current 831 Target mean = 42.5

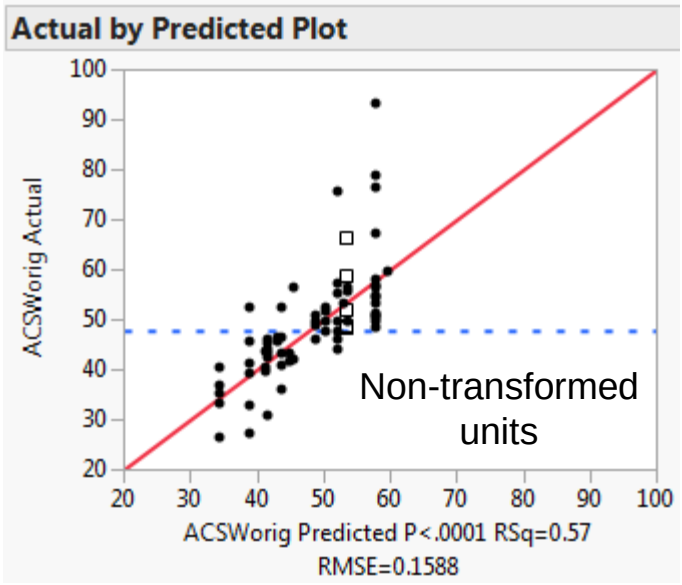
Levels not connected by same letter are significantly different.

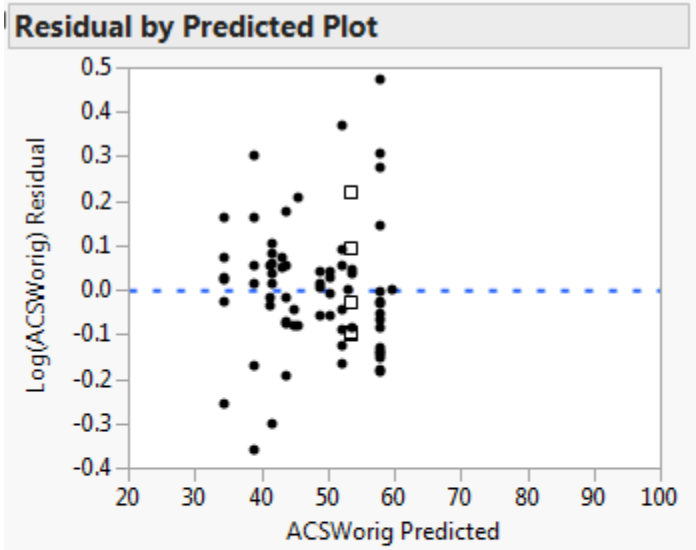
Lubrizol

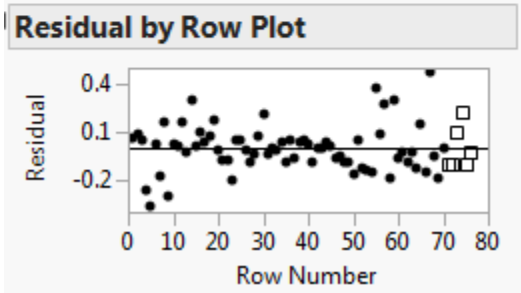
ACSWorig
Model with Camshaft Batch

SUCCESS TOGETHER

All 76 tests utilized; natural logarithm transformation applied: ln(ACSWorig)







Summary of Fit

RSquare	0.56873
RSquare Adj	0.469751
Root Mean Square Error	0.158818
Mean of Response	3.866693
Observations (or Sum Wgts)	76

Source	Prob > F
IND	0.2199
Camshaft Batch	0.6248

Lubrizol

ACSWorig
Model with Camshaft Batch

SUCCESS TOGETHER

All 76 tests utilized; natural logarithm transformation applied: Ln(ACSWorig)

No significant difference among oil and camshaft batches in this model

Source	Prob > F
IND	0.2199
Camshaft Batch	0.6248

Level		Least Sq Mean
831-2	A	54.760242
PC10B	A	50.017390
831-1	A	49.176284
831	A	47.038051
830-2	A	46.815290
PC10E	A	41.312284

Level		Least Sq Mean
D	A	58.387767
F	A	52.438851
G	A	51.845994
J	A	50.894601
E	A	49.123021
H	A	47.592117
K	A	46.840448
C	A	43.859111
B	A	42.092319
A	A	39.874763

Non-transformed units shown;
Comparisons made in transformed units

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	3.8715122	0.056165	68.93	<.0001*	.
IND[830-2]	-0.025302	0.082315	-0.31	0.7596	2.3858964
IND[831-1]	0.0238993	0.071374	0.33	0.7389	4.3688779
IND[831-2]	0.1314522	0.090814	1.45	0.1529	6.6210938
IND[PC10B]	0.0408585	0.050714	0.81	0.4236	1.5711059
IND[PC10E]	-0.150352	0.082315	-1.83	0.0727	2.3858964
Camshaft Batch[A]	-0.185769	0.102265	-1.82	0.0742	9.1653947
Camshaft Batch[B]	-0.131647	0.079614	-1.65	0.1034	4.1892966
Camshaft Batch[C]	-0.09053	0.082721	-1.09	0.2781	2.6986382
Camshaft Batch[D]	0.1955942	0.147392	1.33	0.1894	5.745722
Camshaft Batch[E]	0.0228156	0.081182	0.28	0.7796	2.5991645
Camshaft Batch[F]	0.0881355	0.090951	0.97	0.3364	2.9127878
Camshaft Batch[G]	0.0767655	0.147392	0.52	0.6044	5.745722
Camshaft Batch[H]	-0.008845	0.081182	-0.11	0.9136	2.5991645
Camshaft Batch[J]	0.0582446	0.058632	0.99	0.3244	3.5077171

Collinearity in data affects oil and camshaft batch significance

This will be shown using other models on the following slides

Lubrizol

ACSWorig
Models with Camshaft Batch

SUCCESS TOGETHER

Model Summary of Fit	All data; Oil & Cam included	All data; Oil included	All data; Cam included	4 tests removed; Oil & Cam included	4 tests removed; Oil included	4 tests removed; Cam included
RSquare	0.56873	0.51834	0.51752	0.620013	0.548367	0.563126
RSquare Adj	0.469751	0.483936	0.451728	0.526683	0.514152	0.499709
Root Mean Square Error	0.158818	0.156679	0.161494	5.579579	5.652958	5.736364
Mean of Response	3.866693	3.866693	3.866693	47.15278	47.15278	47.15278
Observations (or Sum Wgts)	76	76	76	72	72	72

Model

Source	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F	Prob > F
IND	0.2199	<.0001*	<.0001*	0.1478	<.0001*	<.0001*
Camshaft Batch	0.6248			0.3166		

Term	Prob>|t|	VIF	Prob>|t|	VIF	Prob>|t|	VIF	Prob>|t|	VIF	Prob>|t|	VIF	Prob>|t|	VIF
Intercept	<.0001*	.	<.0001*	.	<.0001*	.	<.0001*	.	<.0001*	.	<.0001*	.
IND[830-2]	0.7596	2.3858964	0.0540	1.1900205	<.0001*	1.7424641	0.9007	2.392087	0.0571	1.1913192	<.0001*	1.736
IND[831-1]	0.7389	4.3688779	<.0001*	1.0716944	0.0074*	1.7856129	0.8152	4.2347915	<.0001*	1.0625337	0.0006*	1.7850432
IND[831-2]	0.1529	6.6210938	<.0001*	1.0768831	0.2353	2.3314773	0.1589	6.4442014	<.0001*	1.0736467	0.1284	2.3316207
IND[PC10B]	0.4236	1.5711059	0.8210	1.0861862	0.2167	5.5662017	0.3268	1.5758234	0.8584	1.0837142	0.0650	5.5515079
IND[PC10E]	0.0727	2.3858964	<.0001*	1.1900205	0.8864	2.3314773	0.0605	2.392087	<.0001*	1.1913192	0.8875	2.3316207
Camshaft Batch[A]	0.0742	9.1653947			0.3909	2.6737814	0.0191*	9.1406374			0.2266	2.6725404
Camshaft Batch[B]	0.1034	4.1892966			0.6601	5.5662017	0.0265*	4.199001			0.5506	5.5515079
Camshaft Batch[C]	0.2781	2.6986382			0.7945	2.3314773	0.1440	2.7063824			0.6723	2.3316207
Camshaft Batch[D]	0.1894	5.745722			0.0064*	1.7427612	0.0494*	5.7356936			0.1384	1.7333715
Camshaft Batch[E]	0.7796	2.5991645					0.7400	2.6069379				
Camshaft Batch[F]	0.3364	2.9127878					0.1742	2.9182495				
Camshaft Batch[G]	0.6044	5.745722					0.4777	5.7356936				
Camshaft Batch[H]	0.9136	2.5991645					0.8283	2.6069379				
Camshaft Batch[J]	0.3244	3.5077171					0.9145	3.4419562				

ACSWorig
Models with Camshaft Batch

SUCCESS TOGETHER

	All data; Oil & Cam included	All data; Oil included	All data; Cam included	4 tests removed; Oil & Cam included	4 tests removed; Oil included	4 tests removed; Cam included
Oil						
Camshaft Batches						
Estimated Cam K (or 831-2) mean (transformed units)	53.4 (3.9782)	56.7 (4.03857)	53.4 (3.9782)	53.8	53.8	53.8

All data; Oil & Cam included — Oil

Level		Least Sq Mean
831-2	A	54.760242
PC10B	A	50.017390
831-1	A	49.176284
831	A	47.038051
830-2	A	46.815290
PC10E	A	41.312284

All data; Oil & Cam included — Camshaft Batches

Level		Least Sq Mean
D	A	58.387767
F	A	52.438851
G	A	51.845994
J	A	50.894601
E	A	49.123021
H	A	47.592117
K	A	46.840448
C	A	43.859111
B	A	42.092319
A	A	39.874763

All data; Oil included — Oil

Level				Least Sq Mean
831-2	A			56.745141
831-1	A	B		50.399515
PC10B			C	43.094815
831		B	C D	41.235929
830-2			C D	38.878495
PC10E			D	34.308437

All data; Cam included — Camshaft Batches

Level				Least Sq Mean
D	A	B	C	59.800000
J	A			56.000358
F	A	B		53.707197
K	A	B		53.420754
G	A	B	C	53.100000
E	A	B	C	50.311166
H	A	B	C	48.743234
C	A	B	C	45.302462
B		B	C	42.986713
A			C	38.122764

4 tests removed; Oil & Cam included — Oil

Level		Least Sq Mean
831-2	A	53.514848
PC10B	A	50.577266
831-1	A	49.397266
830-2	A	48.443932
831	A	47.648932
PC10E	A	43.260599

4 tests removed; Oil & Cam included — Camshaft Batches

Level		Least Sq Mean
D	A	59.209875
F	A	53.209875
G	A	52.509875
E	A	49.759875
K	A	49.108959
J	A	49.038446
H	A	48.184875
C	A	44.494875
B	A	42.424875
A	A	40.129875

4 tests removed; Oil included — Oil

Level				Least Sq Mean
831-2	A			53.768421
831-1	A	B		49.766667
PC10B			C	43.507143
831		B	C D	41.266667
830-2			C D	39.766667
PC10E			D	34.583333

4 tests removed; Cam included — Camshaft Batches

Level				Least Sq Mean
D	A	B		59.800000
K	A			53.816667
F	A	B		53.800000
G	A	B	C	53.100000
J	A			52.305000
E	A	B		50.350000
H	A	B	C	48.775000
C	A	B	C	45.675000
B		B	C	43.181818
A			C	38.750000

Estimated means differ from current oil target in all models

Current 831 Target mean = 42.5

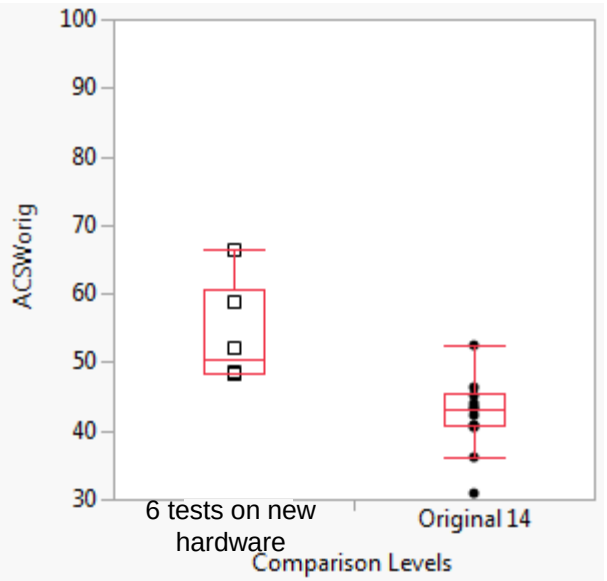
Levels not connected by same letter are significantly different.

Lubrizol

ACSWorig
Non-Model based comparison

SUCCESS TOGETHER

Original Target vs. Latest 6 Tests

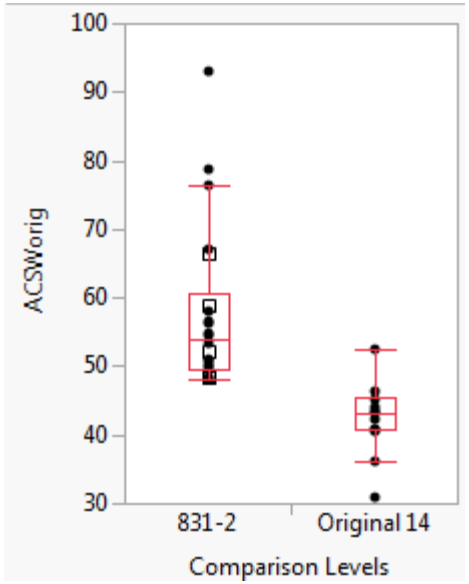


Means and Std Deviations

Level	Number	Mean	Std Dev
6 tests on new hardware	6	53.8167	7.39552
Original 14	14	42.4857	4.98796

Means significantly differ;
No significant difference in variances

Original Target vs. 831-2 Tests

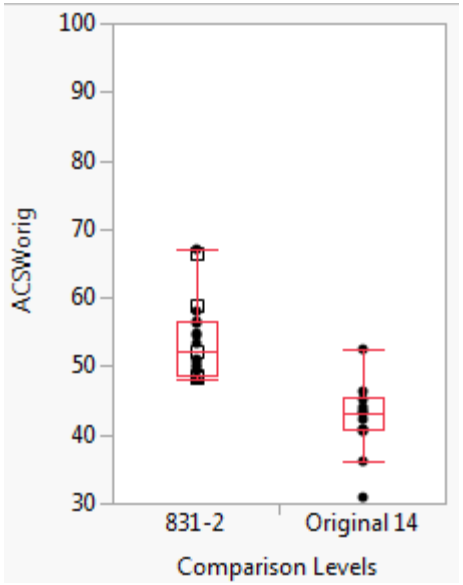


Means and Std Deviations

Level	Number	Mean	Std Dev
831-2	22	57.7182	11.8093
Original 14	14	42.4857	4.9880

Means significantly differ;
Variances significantly differ

Original Target vs. 831-2 Tests; 3 tests excluded



Means and Std Deviations

Level	Number	Mean	Std Dev
831-2	19	53.7684	5.72820
Original 14	14	42.4857	4.98796

Means significantly differ;
No significant difference in variances

Lubrizol

Summary
ATWL

SUCCESS TOGETHER

No significant difference between the original oil targets and new hardware estimates

	Model Terms					
Number of Tests	Lab/stand	Oil	Tappet Batch	Camshaft Batch	Estimated New Hardware Mean	Estimated Standard Deviation
76; all data	x	Blends included	x		87.8	16.72
76; all data	x	Blends combined	x		88.7	17.64
73; Lab F removed	x	Blends included	x		87.5	16.5
73; Lab F removed	x	Blends combined	x		87.8	17.4
76; all data	x	Blends included		x	87.4	13.3
76; all data	x	Blends combined		x	86.5	13.25
73; Lab F removed	x	Blends included		x	85.4	13.21
73; Lab F removed	x	Blends combined		x	85.3	13.16
20	New hardware vs. 14 tests used to calculate current oil targets				84.1	12.57

Current Oil Target Mean = 97.2;
Current Oil Target Standard Deviation = 14.8

Lubrizol

Summary
ACSW

SUCCESS TOGETHER

There is a significant difference between the original oil target and new hardware estimated means

	Model Terms							
Number of Tests	Lab/stand	Oil	Tappet Batch	Camshaft Batch	Transformation	Estimated New Hardware Mean	Estimated New Hardware Mean in Natural Units	Estimated Standard Deviation
76; all data		Blends included	x		Natural Log	3.9782	53.4	0.15295
76; all data		Blends combined	x		Natural Log	3.9782	53.4	0.15521
72		Blends included	x		None	53.8	53.8	5.39
72		Blends combined	x		None	53.8	53.8	5.44
76; all data		Blends included		x	Natural Log	3.9782	53.4	0.15882
76; all data		Blends included			Natural Log	4.03857	56.7	0.15668
76; all data				x	Natural Log	3.9782	53.4	0.16149
72		Blends included		x	None	53.8	53.8	5.58
72		Blends included			None	53.8	53.8	5.65
72				x	None	53.8	53.8	5.74
20	New hardware vs. 14 tests used to calculate current oil targets				None	53.8	53.8	7.4

831-2 estimated means since only Oil is in the model

Number of Tests	Comparison	Estimated 831-2 Mean	Estimated 831-2 Standard Deviation
36	14 tests used to calculate current oil targets vs. 831-2 Tests	57.7	11.8
33	14 tests used to calculate current oil targets vs. 831-2 Tests; 3 Tests Removed	53.8	5.7

Current Oil Target Mean = 42.5;
Current Oil Target Standard Deviation = 5.0

Lubrizol

ACSW
Correction Factor Options

SUCCESS TOGETHER

Option 1: Assume test precision has NOT changed

Use estimates based on model with camshaft batch

Four tests excluded

	Model Terms							
Number of Tests	Lab/stand	Oil	Tappet Batch	Camshaft Batch	Transformation	Estimated New Hardware Mean	Estimated New Hardware Mean in Natural Units	Estimated Standard Deviation
72				x	None	53.8	53.8	5.74

Current Oil Target Mean = 42.5

CF: ACSWorig – 11.3 (where 11.3 = 53.8 – 42.5)

Oil Targets for LTMS remain unchanged:

Standard Deviation: 5.0

Mean: 42.5

Lubrizol

ACSW
Correction Factor Options

SUCCESS TOGETHER

Option 2: Assume test precision has changed and will continue to be different

Use estimates based on model with camshaft batch

All data included

	Model Terms							
Number of Tests	Lab/stand	Oil	Tappet Batch	Camshaft Batch	Transformation	Estimated New Hardware Mean	Estimated New Hardware Mean in Natural Units	Estimated Standard Deviation
76; all data				x	Natural Log	3.9782	53.4	0.16149

Current Oil Target Mean = 42.5 (3.7423 in ln units)

CF: ln(ACSWorig) – 0.2359

Modify Oil Targets for LTMS (natural log units):

Standard Deviation: 0.16149

Mean: 3.7423

Lubrizol

ACSW
Correction Factor Options

SUCCESS TOGETHER

Option 3: Assume change is related to oil batch change and NOT hardware

Use estimates based on model with Oil Blends

All data included

Number of Tests	Lab/stand	Oil	Tappet Batch	Camshaft Batch	Transformation	Estimated Oil Mean	Estimated Oil Mean in Natural Units	Estimated Standard Deviation
76; all data		Blends included			Natural Log	4.03857	56.7	0.15668

Current Oil Target Mean = 42.5

Modify Oil Targets for LTMS (natural log units):

Standard Deviation: 0.15668

Mean: 4.03857

We could also use non-model based estimates

Number of Tests	Comparison	Estimated 831-2 Mean	Estimated 831-2 Standard Deviation
36	14 tests used to calculate current oil targets vs. 831-2 Tests	57.7	11.8

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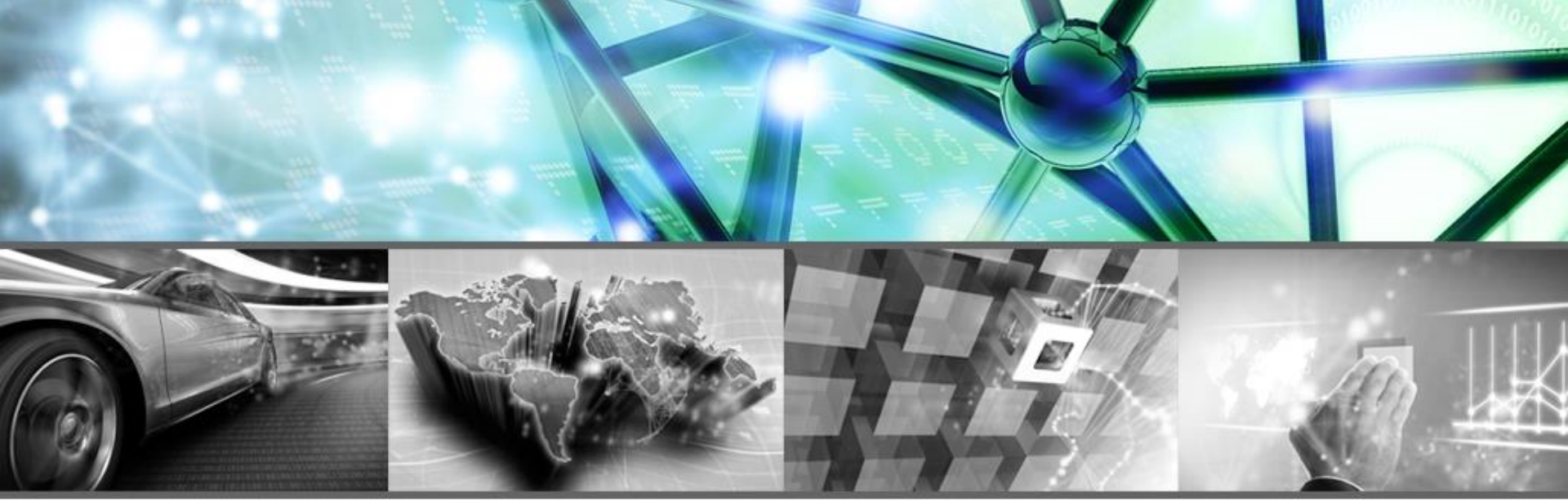

SUCCESS TOGETHER

Working together, achieving great things

When your company and ours combine energies, great things can happen. You bring ideas, challenges and opportunities. We'll bring powerful additive and market expertise, unmatched testing capabilities, integrated global supply and an independent approach to help you differentiate and succeed.

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APPENDIX A

Relationship between Fuel Batches, Engines, Tappet Batches, Camshaft Batches, and Oils

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Fuel Batch by Engine

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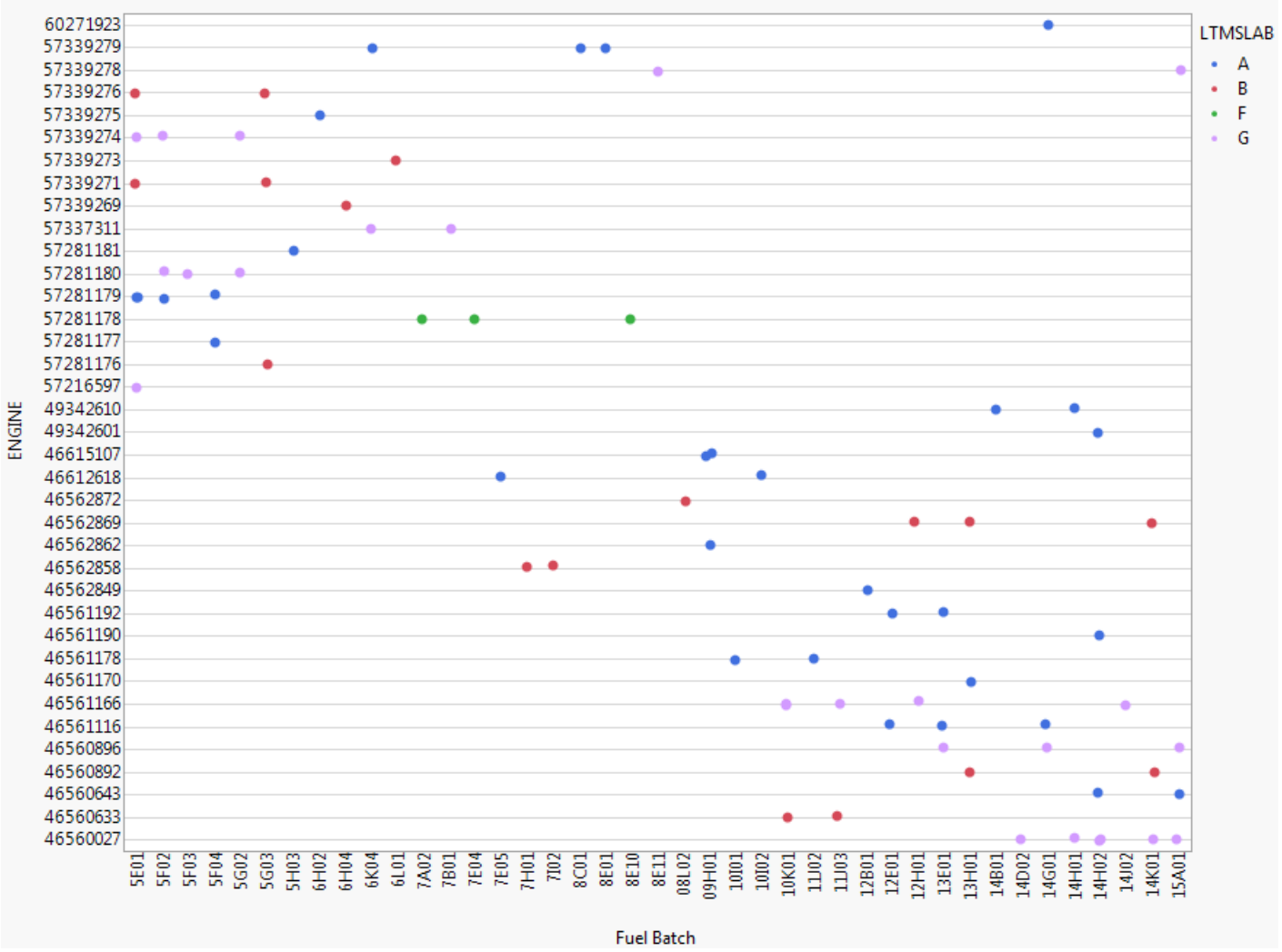
As expected:

1. Each engine is associated with a single lab
2. Each Fuel Batch is used in a subset of the engines
3. Many Fuel Batches are only used in a subset of the labs

It is not possible with these data to simultaneously estimate both Engine & Fuel Batch differences



Simultaneous estimation of Fuel Batch and Lab is difficult due to limited Lab F data

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Tappet Batch by Fuel Batch

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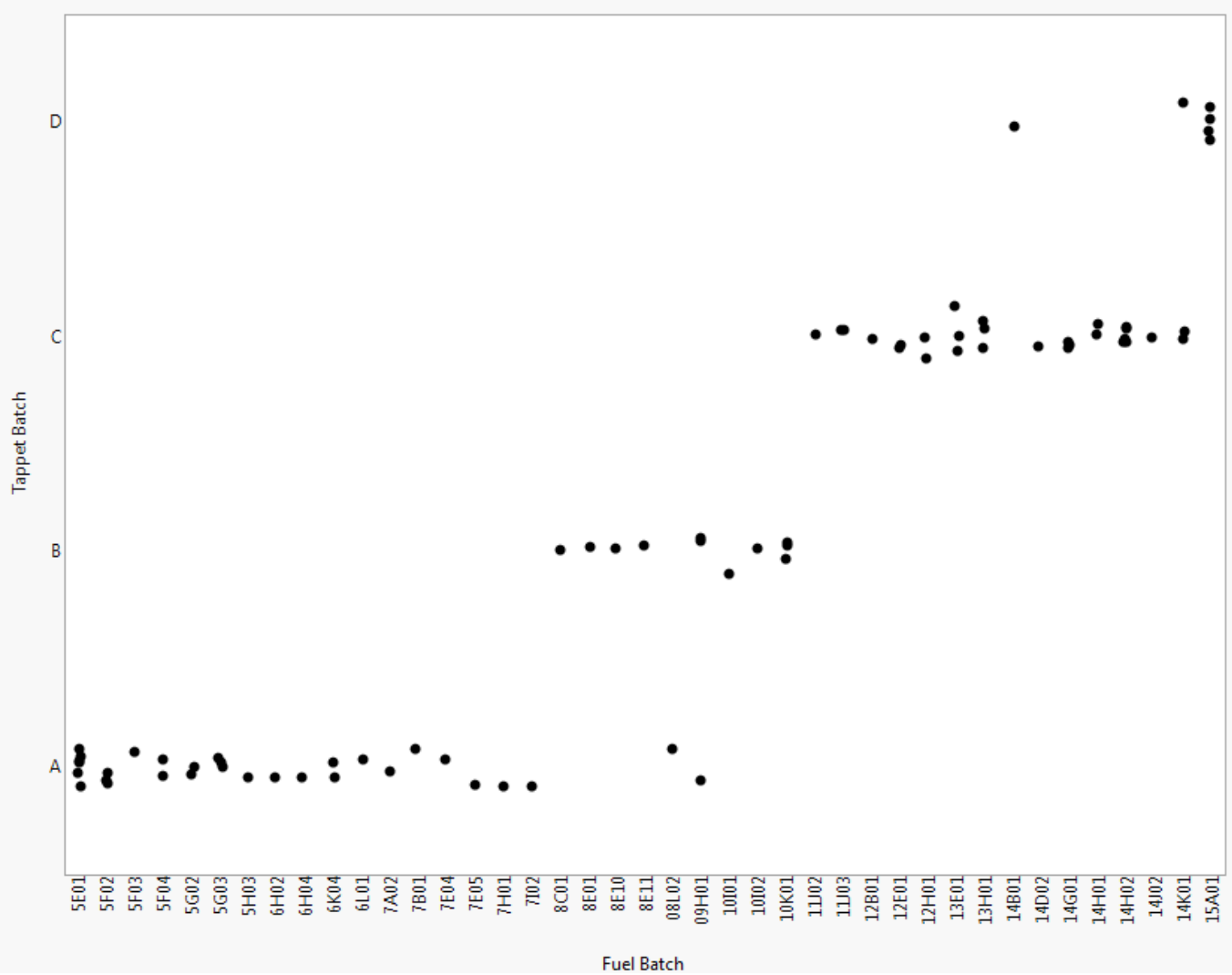
It is not possible with these data to simultaneously estimate Fuel Batch & Tappet Batch differences



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Camshaft Batch by Fuel Batch

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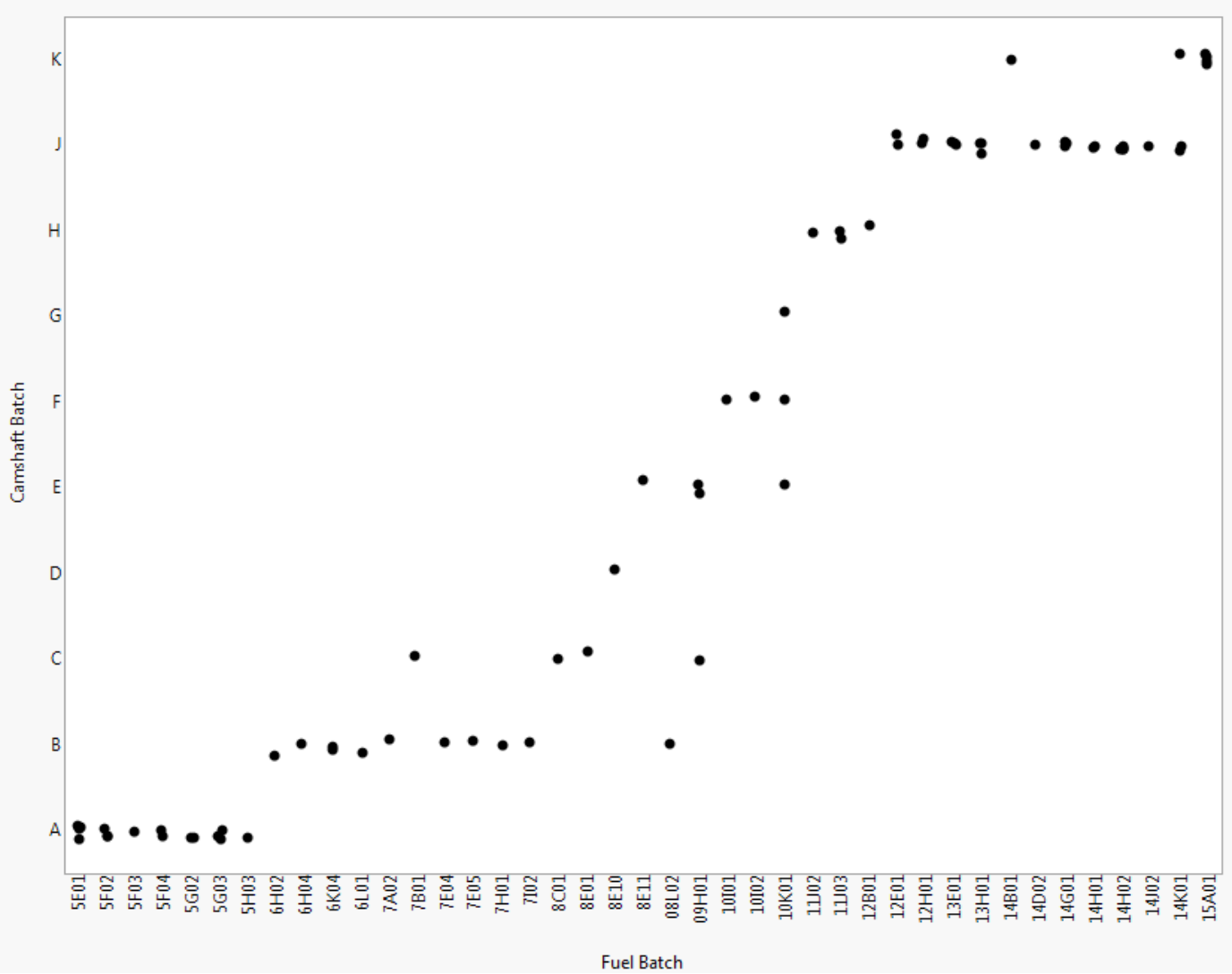
It is not possible with these data to simultaneously estimate Fuel Batch & Camshaft Batch differences



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ACSW & ATWL by Fuel Batch

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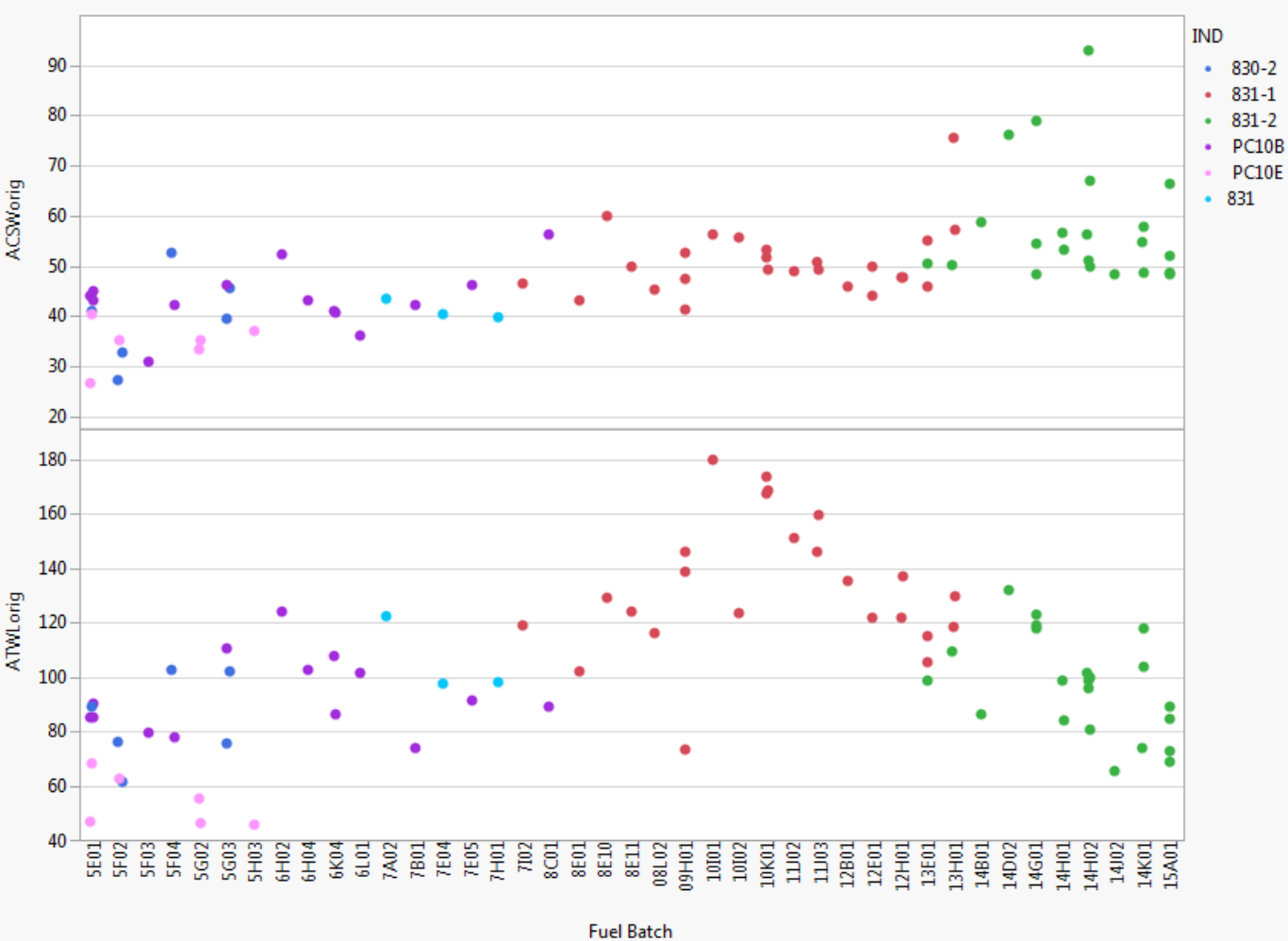
Differences in Oils and their blends may be influenced by differences in Fuel Batches

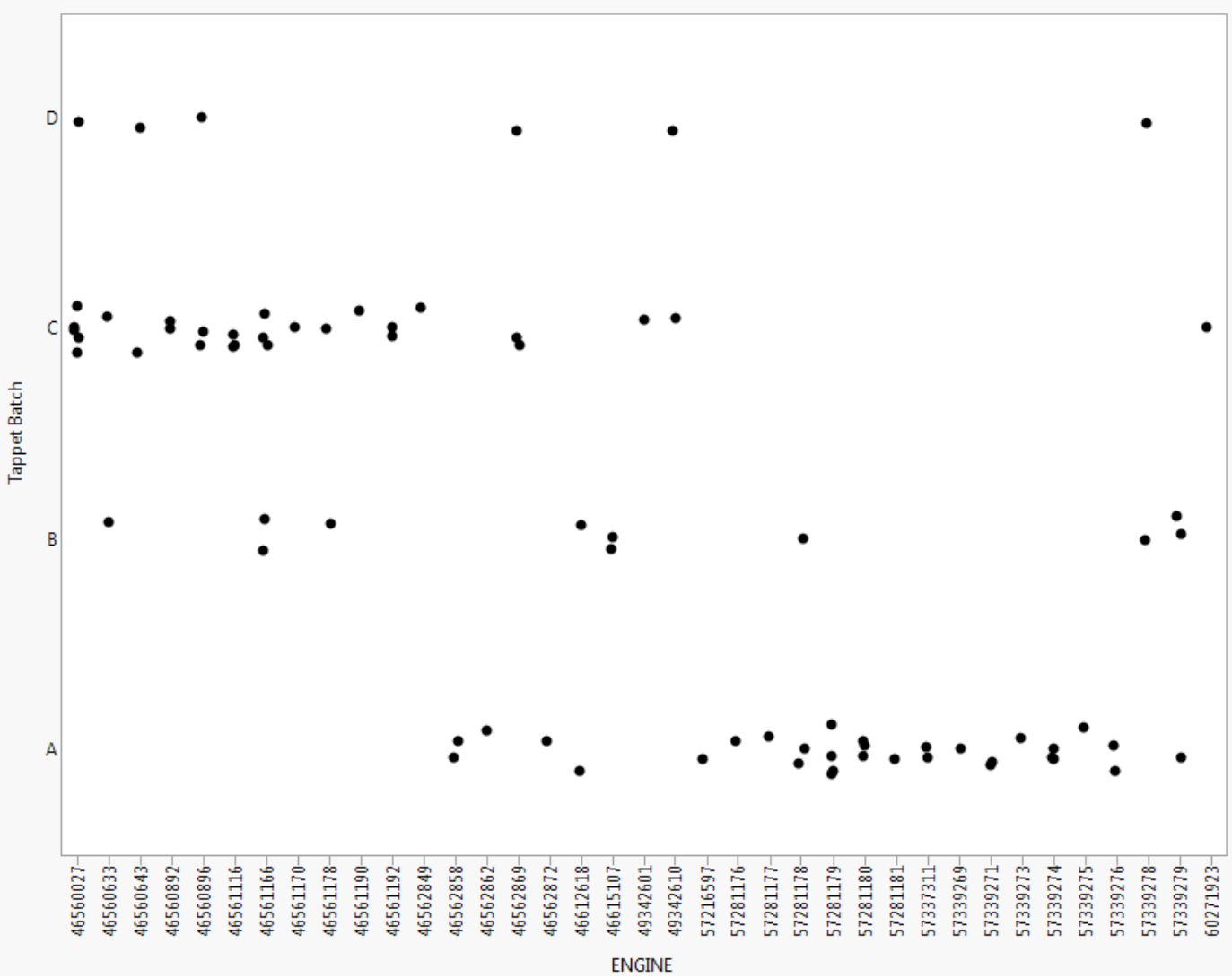


Lubrizol

Tappet Batch by Engine

SUCCESS TOGETHER

It is not possible with these data to simultaneously estimate Engine & Tappet Batch differences

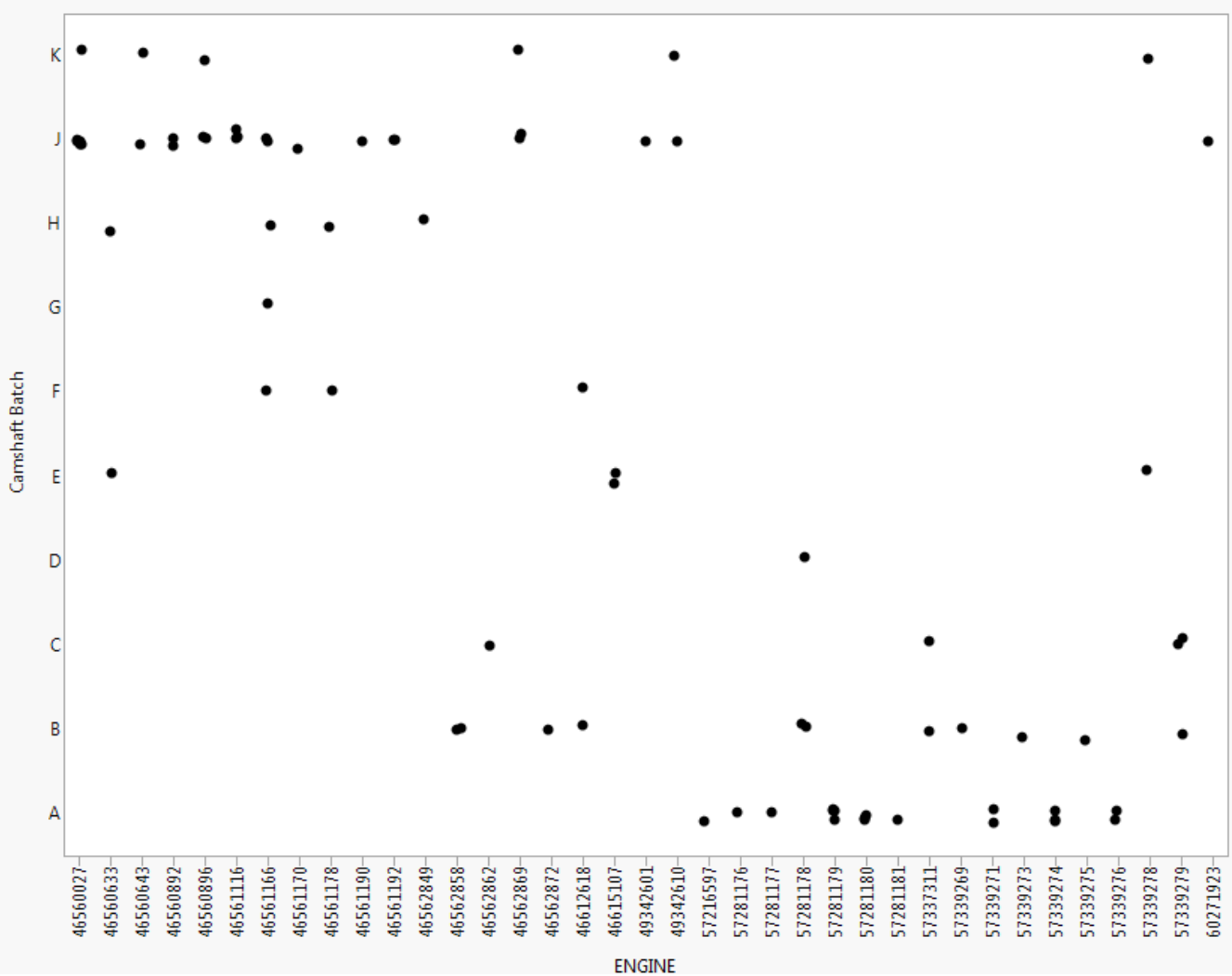


Lubrizol

Camshaft Batch by Engine

SUCCESS TOGETHER

It is not possible with these data to simultaneously estimate Engine & Camshaft Batch differences



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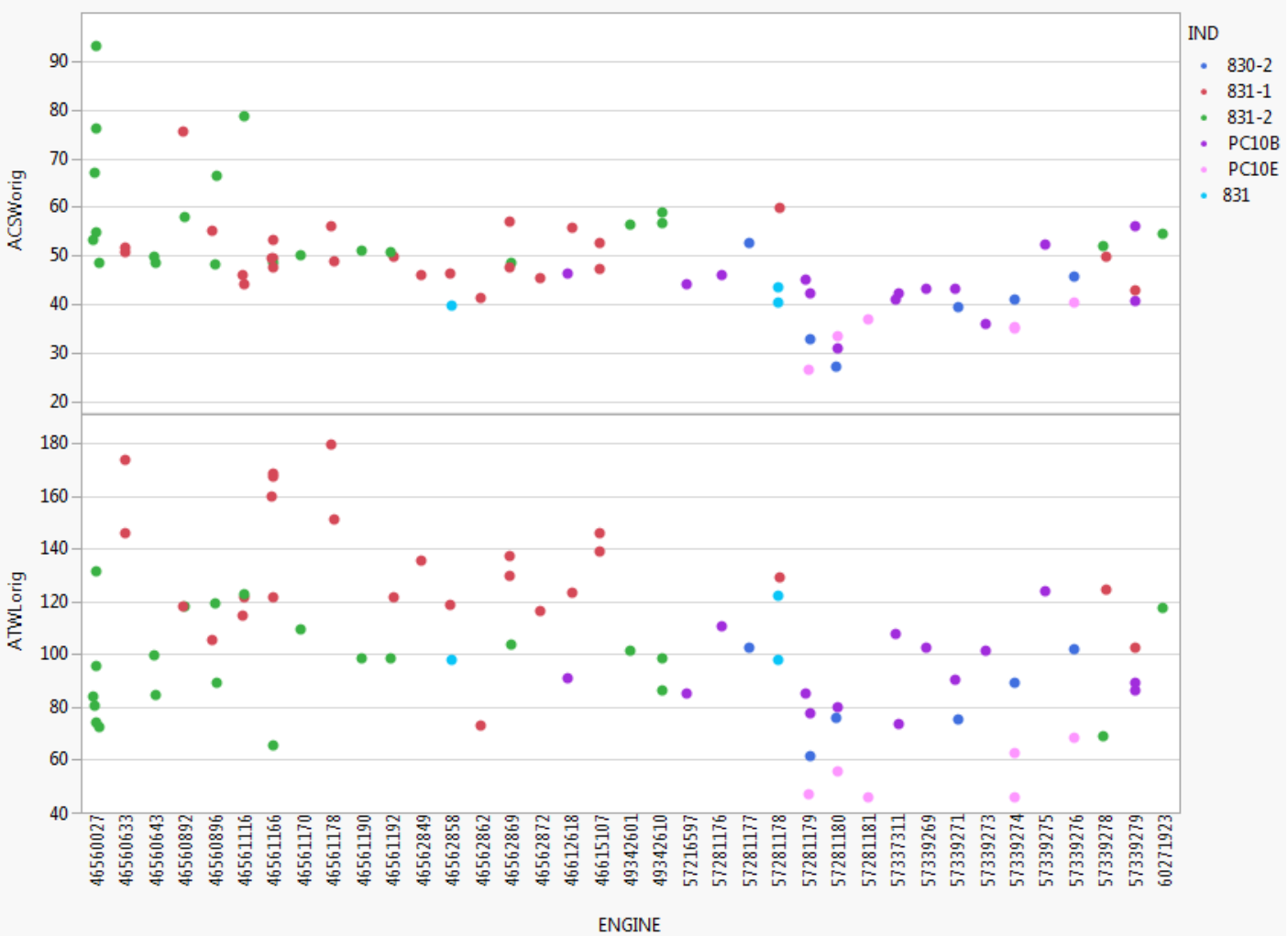
ACSW & ATWL by Engine

SUCCESS TOGETHER

Differences in Oils and their blends may be influenced by differences in Engines

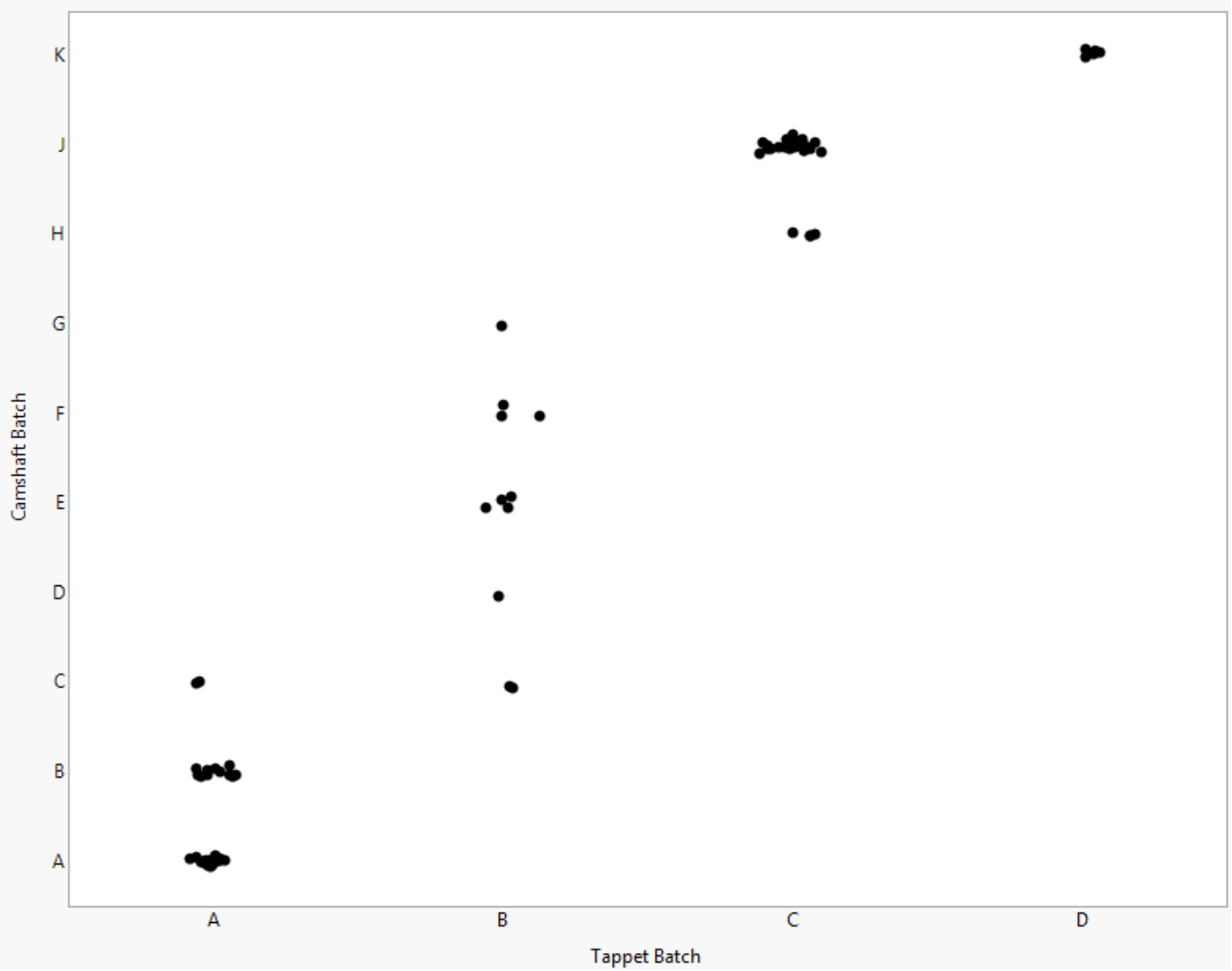


Lubrizol

Camshaft Batch by Tappet Batch

SUCCESS TOGETHER

It is not possible with these data to simultaneously estimate Tappet & Camshaft Batch differences



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APPENDIX B

LTMS Details

&

Hardware History

Lubrizol

Current State of LTMS for ISB

SUCCESS TOGETHER

LTMS file contains test results from 20041115 to 20150315

Severity adjustments are not currently applicable

1. These would affect candidate results only

Values used in ISB LTMS calculations

LUBRICANT TEST MONITORING SYSTEM CONSTANTS

		EWMA Chart				Shewhart Chart	
		LAMBDA		K		K	
Chart Level	Limit Type	Precision	Severity	Precision	Severity	Precision	Severity
Stand	Action	0.3	0.3	2.10	2.36	2.10	1.96
Industry	Warning	0.2	0.2	2.10	2.36	--	--
	Action	0.2	0.2	2.80	3.00	--	--

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Current State of LTMS for ISB

SUCCESS TOGETHER

Correction factors are currently in place for:

- Average Tappet Weight Loss (ATWL)
- Average Camshaft Wear (ACSW)

ISB	April 21, 2011	***	All tests using batch B tappets with batch E, F, and G cams	Multiply ATWL by 0.637; Add -9.5 to ACSW
ISB	December 11, 2011	November 12, 2012	All tests using batch C Tappets with batch H cams	Multiply ATWL by 0.637; Add -9.5 to ACSW
ISB	November 13, 2012	***	All tests using batch C tappets with batch H and J cams	Multiply ATWL by 0.711; Add -5.6 to ACSW

History of Reference Oil Targets (831-2 is new batch introduced in 2013)

ISB Reference Oil Targets							
		Effective Dates		Average Camshaft Wear		Average Tappet Weight Loss	
Oil	n	From	To[1]	$\bar{X}$	s	$\bar{X}$	s
821 (PC10E)	6	6-4-05	12-31-05	34.6	4.6	56.2	9.6
830-2	6	6-4-05	12-31-05	39.8	9.0	85.9	16.0
831 (PC10B)	6	6-4-05	1-24-07	41.9	5.6	88.7	15.9
	10	1-25-07	8-6-07	42.8	5.4	94.9	15.3
	14	8-7-07	***	42.5	5.0	97.2	14.8
831-1[2]	--	8-7-07	***	42.5	5.0	97.2	14.8
831-2[2]	--	8-6-13	***	42.5	5.0	97.2	14.8

1 *** = currently in effect
2 Targets based on oil 831

831-1 and 831-2 currently based on 831 targets

Average Camshaft Wear
ACSWzi EWMA Control Chart

SUCCESS TOGETHER

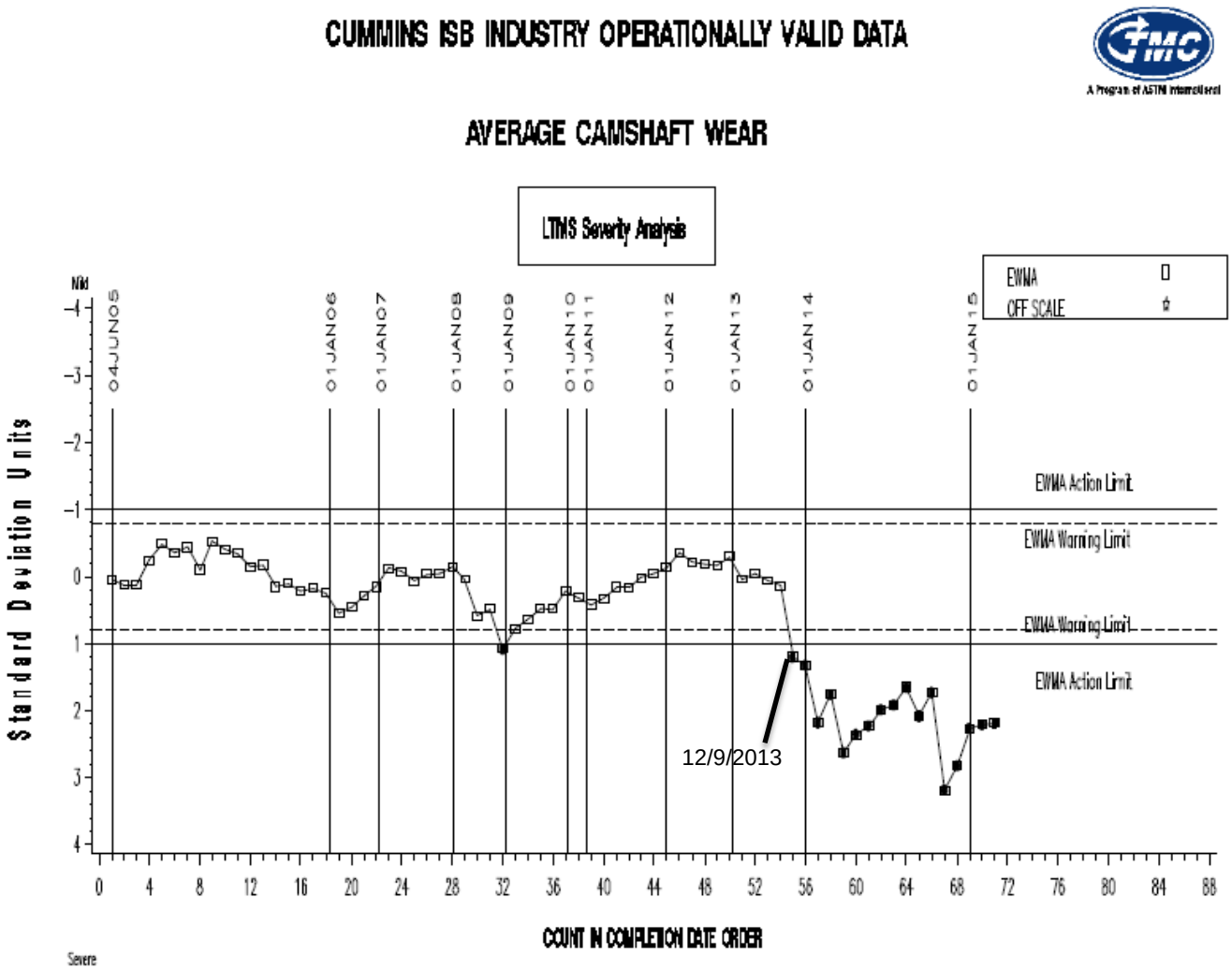

Chart indicates ACSW trending severe since around beginning of 2014

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Average Tappet Weight Loss
ATWLzi EWMA Control Chart

SUCCESS TOGETHER

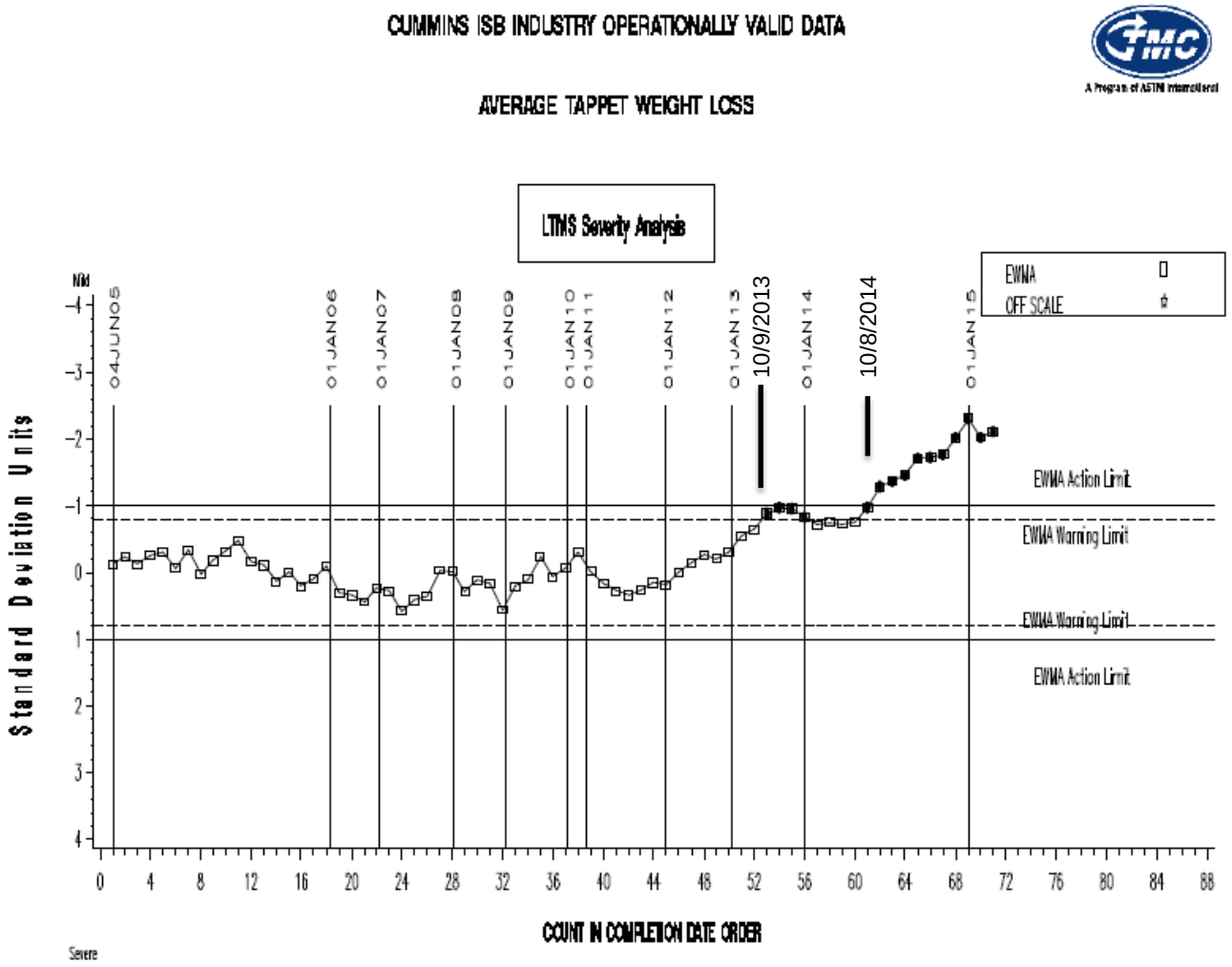

Chart indicates ATWL trending mild since about Oct 2014
(Possibly since Oct 2013)

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Hardware

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Cummins ISB Critical Engine Parts Batch Changes

ISB Camshaft Batch	Starting Kit #	Date
A	1	Jun-2004
B	135	Feb-2006
C	244	Aug-2007
D	290	Jul-2008
E	337	Apr-2009
F	389	Mar-2010
G	441	Mar-2011
H	486	Nov-2011
J	569	Aug-2012
K	821	Jan-2015

ISB Tappet Batch	Starting Kit #	Date
A	1	Jun-2004
B	279	Jan-2008
C	475	Aug-2011
D	821	Jan-2015

ISB Crosshead Batch	Starting Kit #	Date
A	1	Jun-2004
B	279	Jan-2008
C	475	Aug-2011
D	569	Aug-2012

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Pushrod Batches

New pushrods estimated to start with Kit# 556

- 5000 were obtained on June 22, 2012
- We cannot guarantee these 5000 came from the same batch

Prior to new pushrod “batch”, pushrods came in small quantities from different batches

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APPENDIX C

Average Camshaft Wear Graphs

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Average Camshaft Wear
By OIL and LAB

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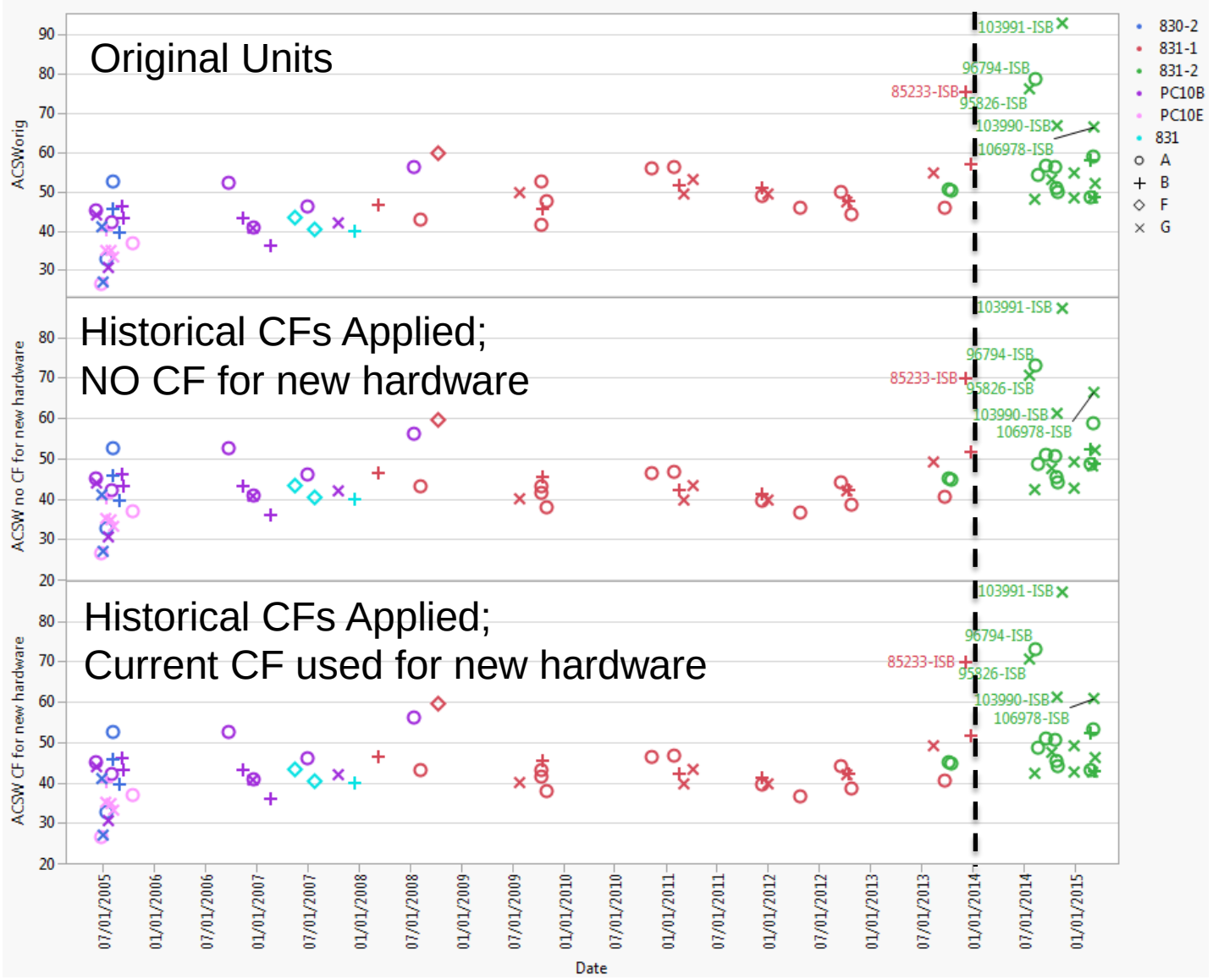

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Average Camshaft Wear By Camshaft Batch

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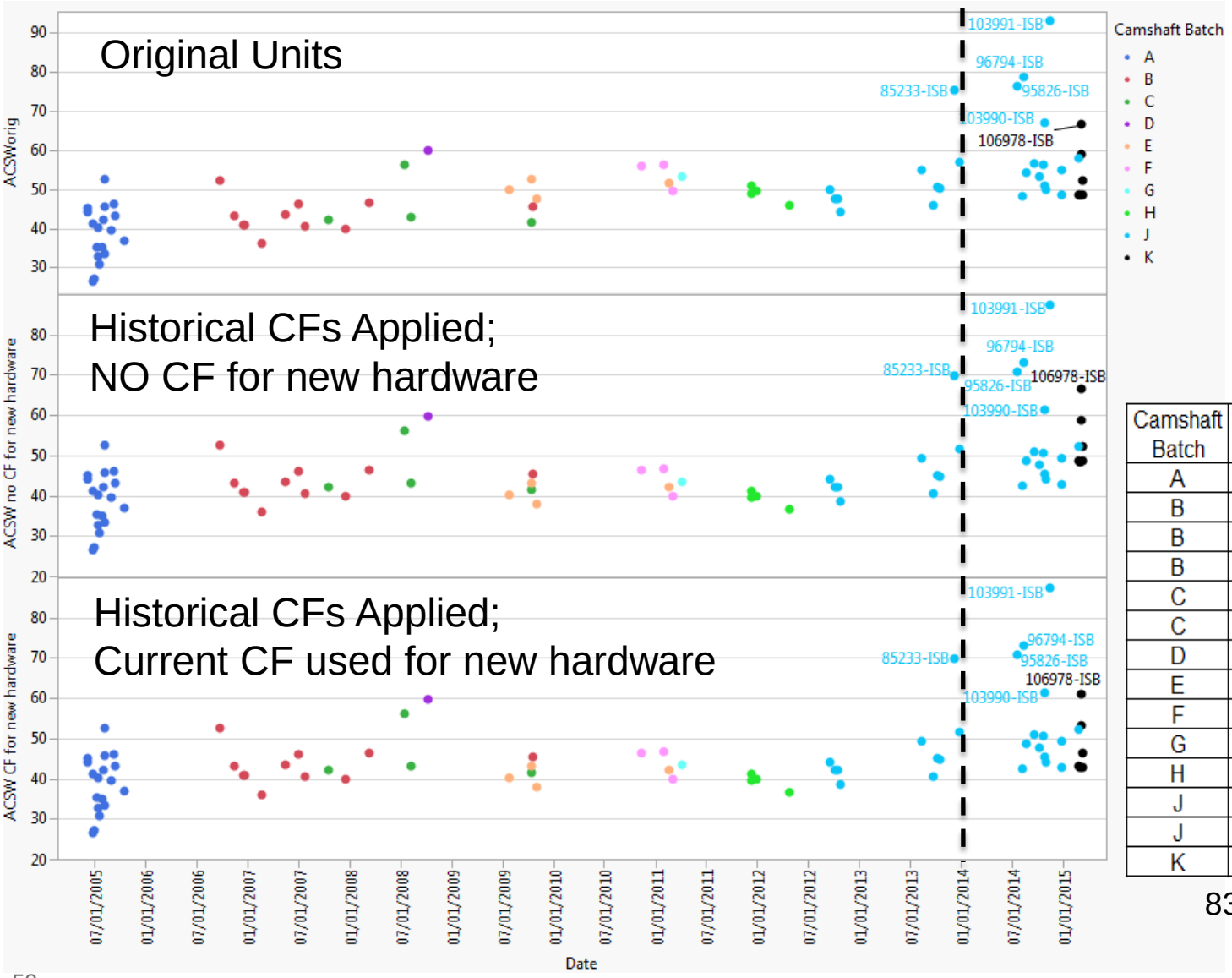

Camshaft Batch	IND	Number of tests	Mean(ACSWorig)
A	PC10B	6	41.9
B	831-1	2	45.9
B	PC10B	6	43.2
B	831	3	41.3
C	831-1	2	42.2
C	PC10B	2	49.2
D	831-1	1	59.8
E	831-1	4	50.4
F	831-1	3	53.8
G	831-1	1	53.1
H	831-1	4	48.8
J	831-1	8	52.9
J	831-2	16	59.2
K	831-2	6	53.8

831 Target mean = 42.5

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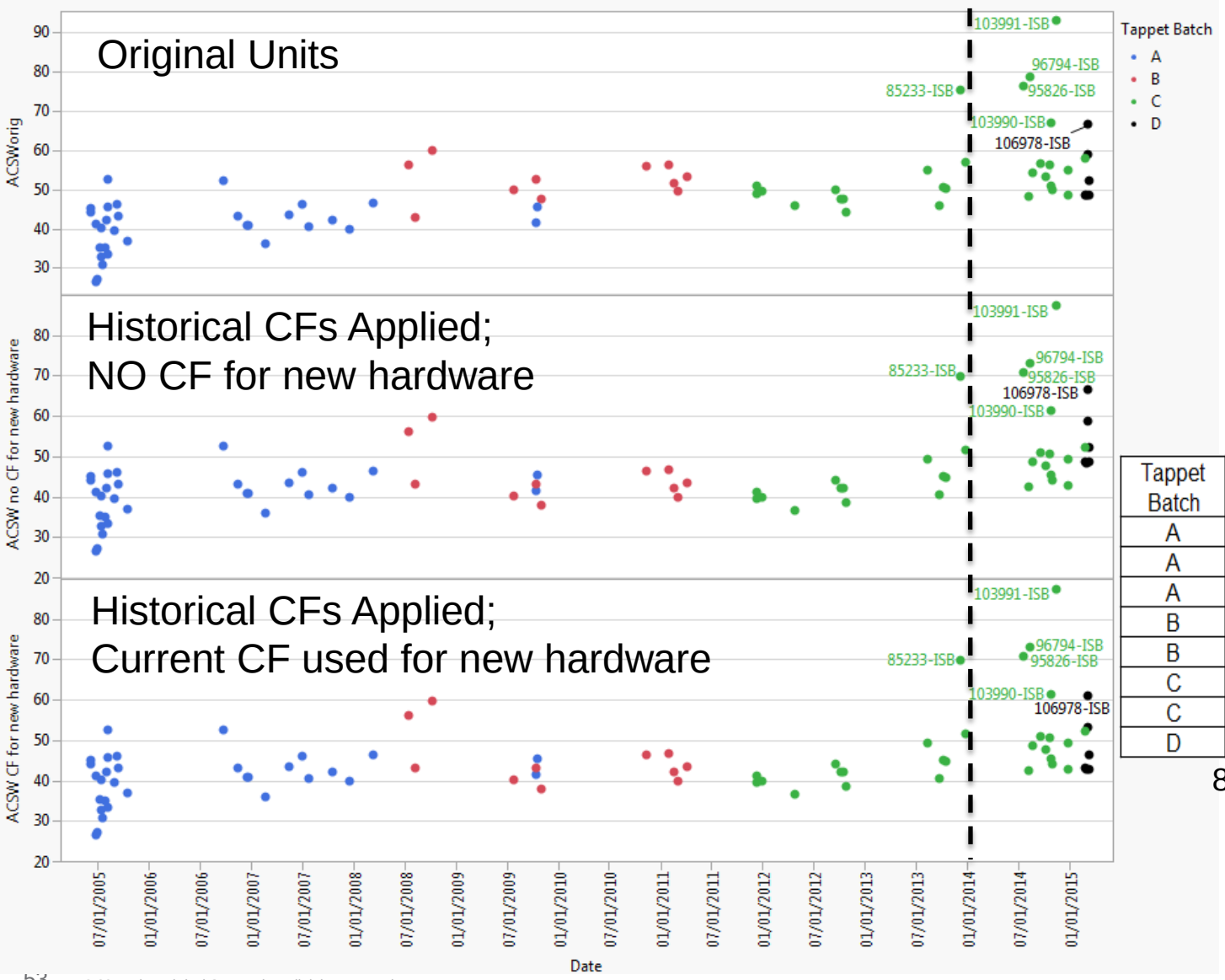
Average Camshaft Wear By Tappet Batch

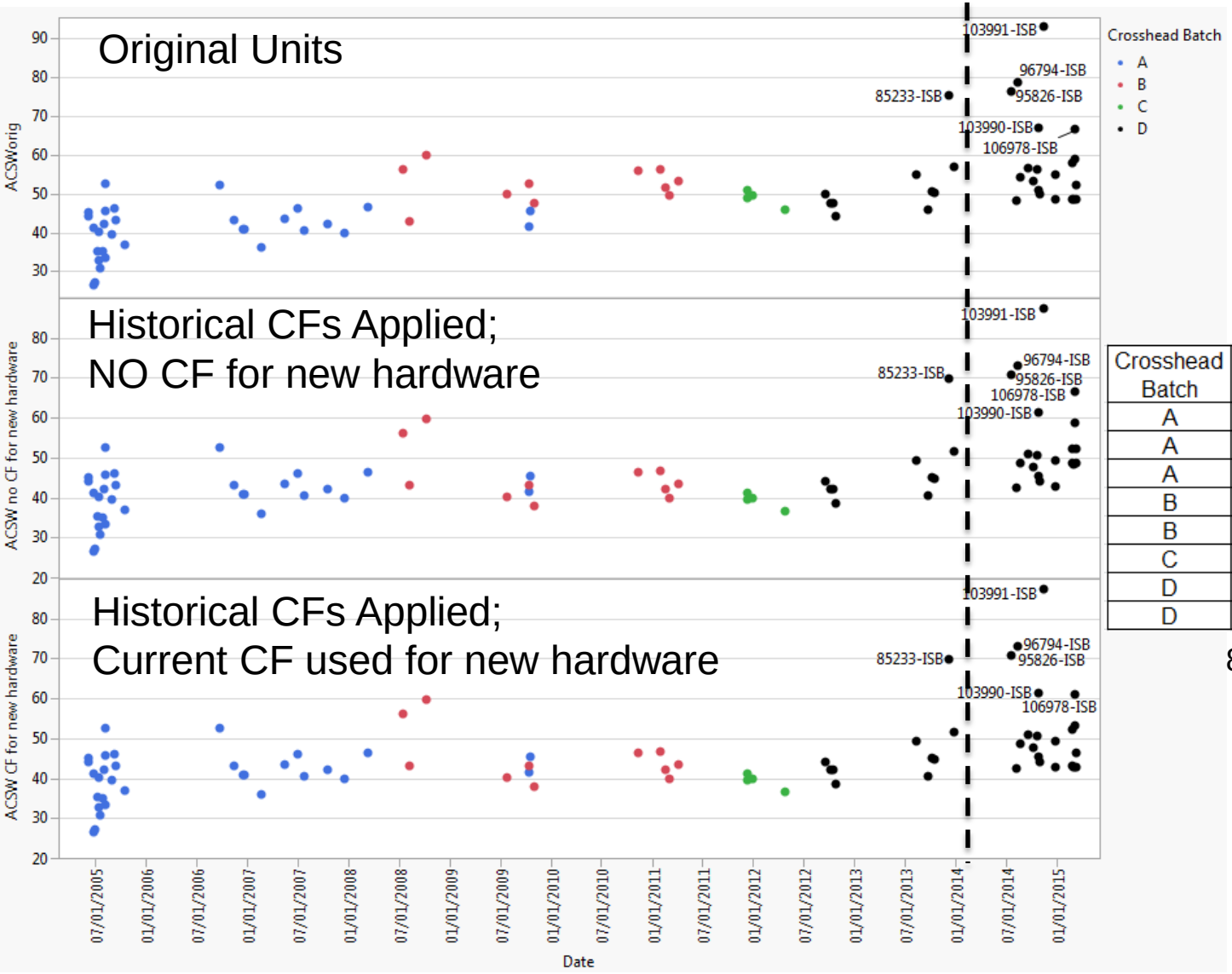


Tappet Batch	IND	Number of tests	Mean(ACSWorig)
A	831-1	3	44.4
A	PC10B	13	42.5
A	831	3	41.3
B	831-1	10	51.9
B	PC10B	1	56.2
C	831-1	12	51.5
C	831-2	16	59.2
D	831-2	6	53.8

831 Target mean = 42.5

Average Camshaft Wear By Crosshead Batch

SUCCESS TOGETHER



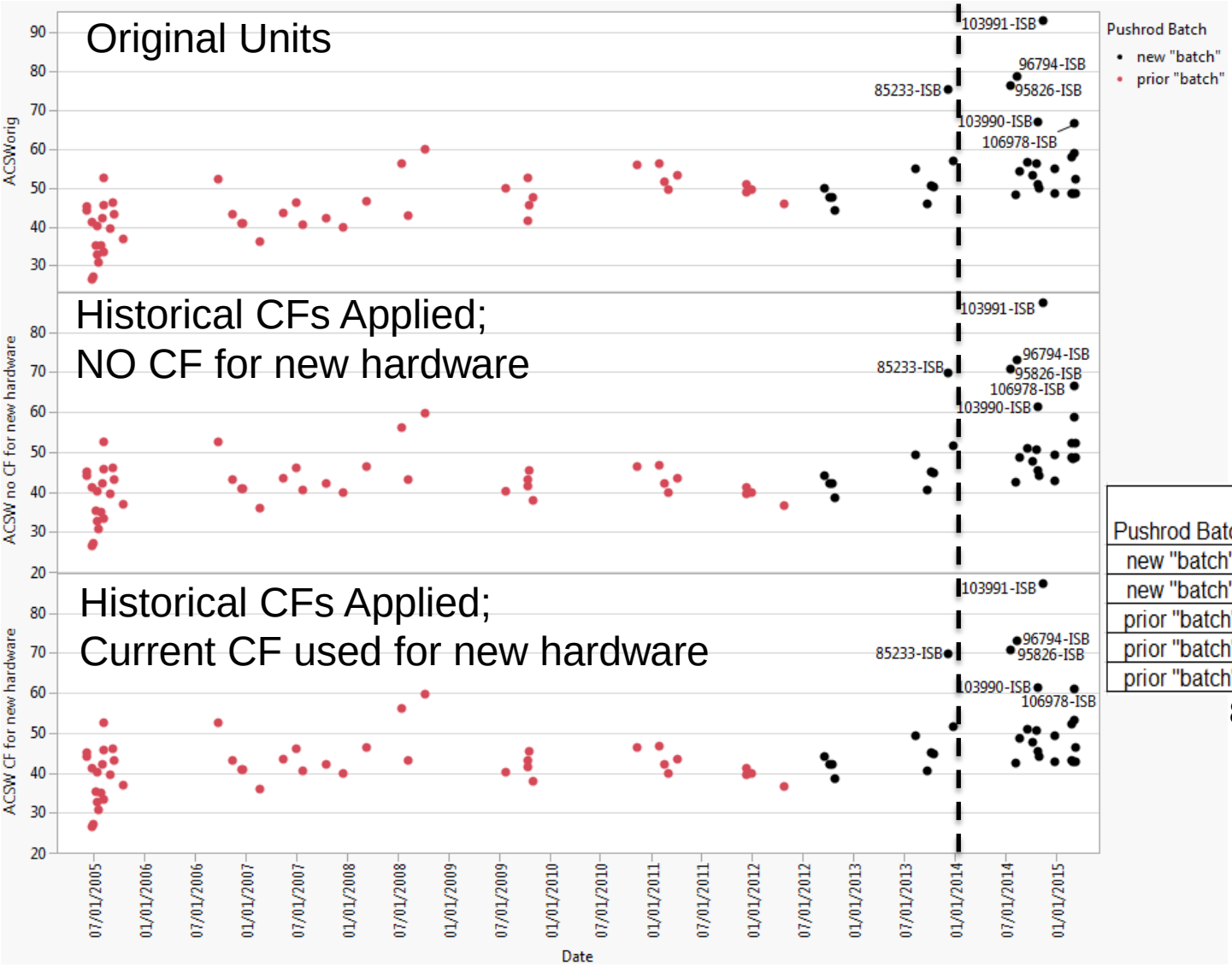
Crosshead Batch	IND	Number of tests	Mean(ACSWorig)
A	831-1	3	44.4
A	PC10B	13	42.5
A	831	3	41.3
B	831-1	10	51.9
B	PC10B	1	56.2
C	831-1	4	48.8
D	831-1	8	52.9
D	831-2	22	57.7

831 Target mean = 42.5

Lubrizol

Average Camshaft Wear By Pushrod "Batch"

SUCCESS TOGETHER



Pushrod Batch	IND	Number of tests	Mean(ACSWorig)
new "batch"	831-1	8	52.9
new "batch"	831-2	22	57.7
prior "batch"	831-1	17	49.8
prior "batch"	PC10B	14	43.5
prior "batch"	831	3	41.3

831 Target mean = 42.5

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APPENDIX D

Average Tappet Weight Loss Graphs

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Average Tappet Weight Loss (ATWLorig): By Oil and Lab

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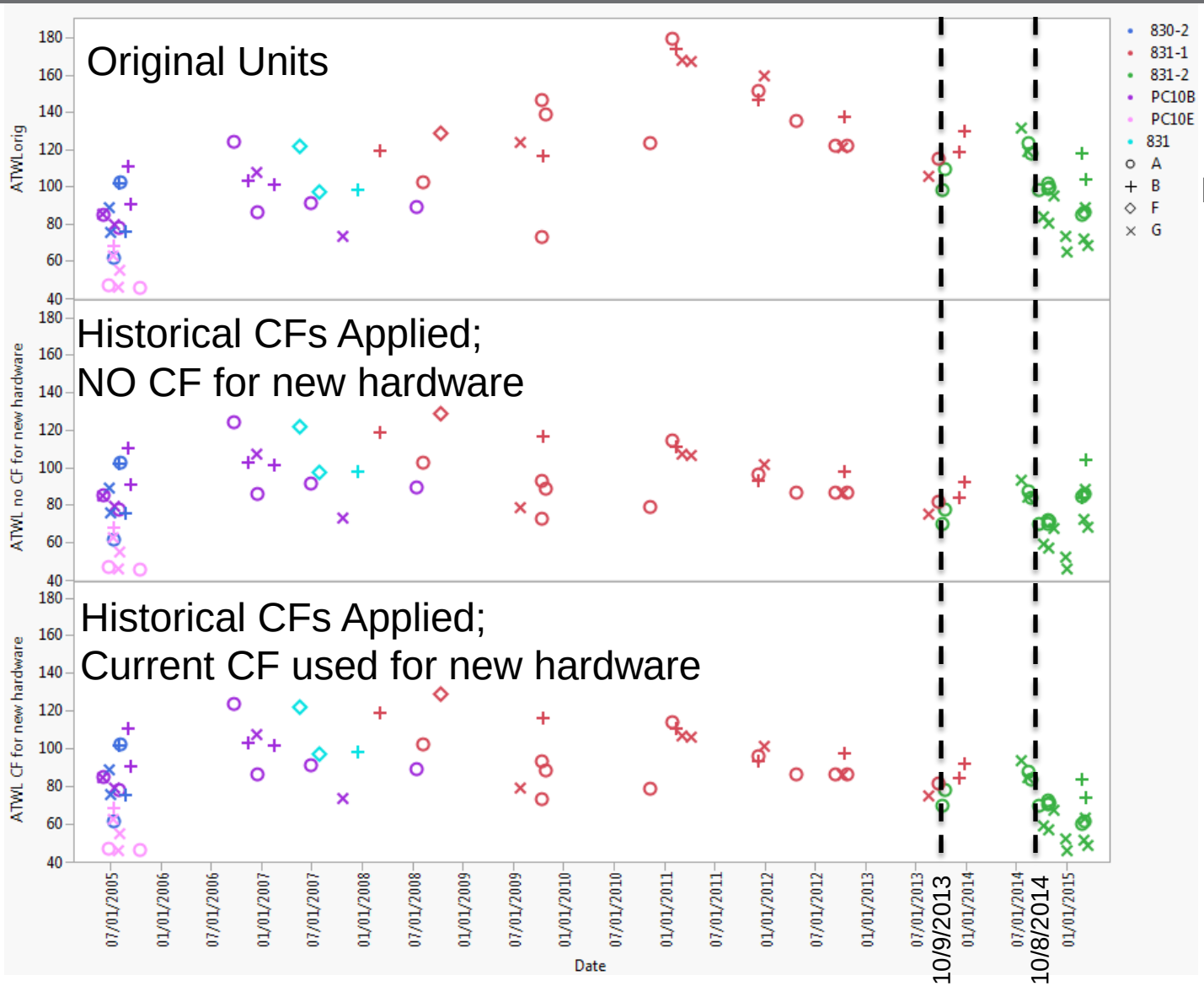

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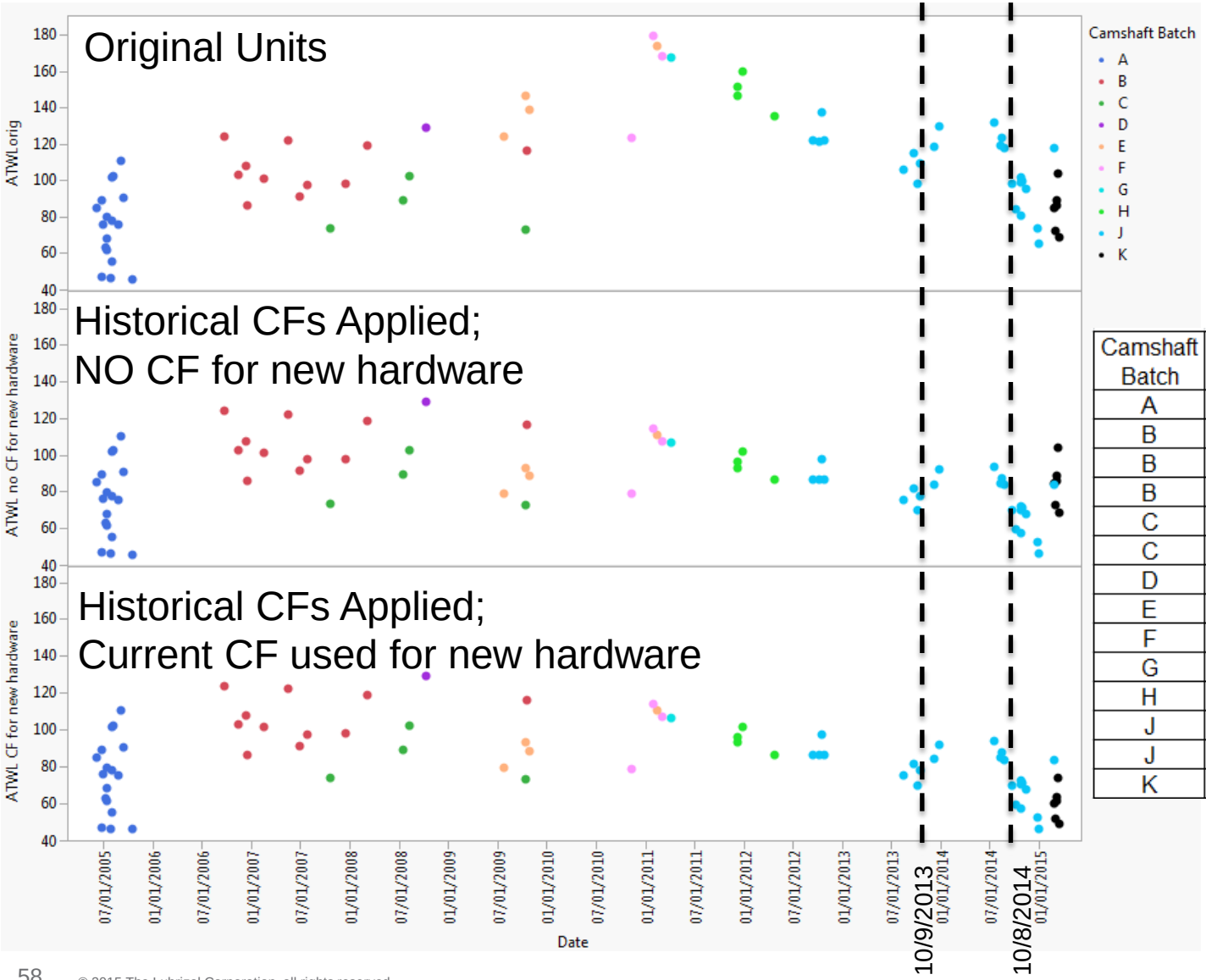
Average Tappet Weight Loss (ATWLorig): By Camshaft Batch

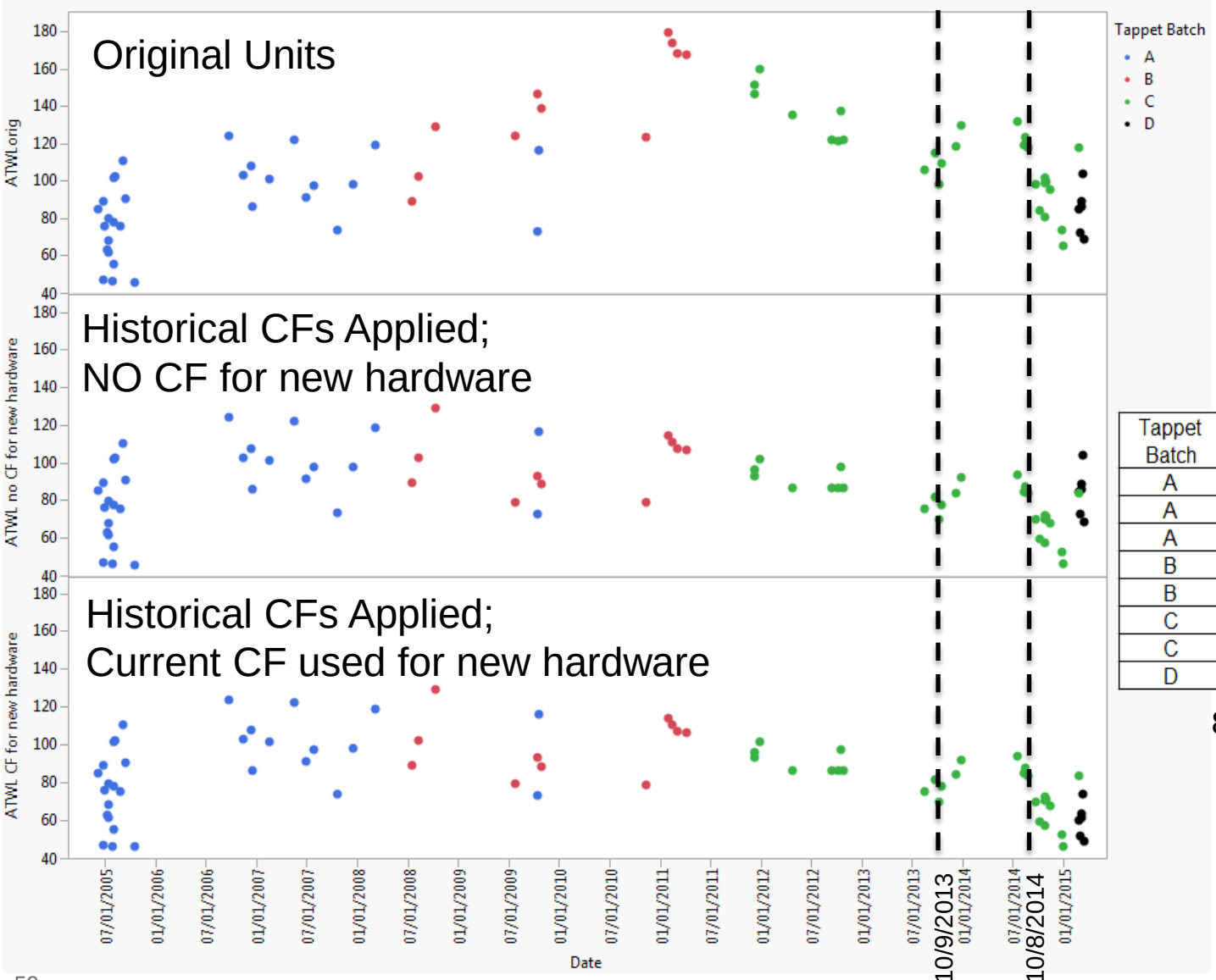


Camshaft Batch	IND	Number of tests	Mean(ATWLorig)
A	PC10B	6	88.1
B	831-1	2	117.5
B	PC10B	6	102.1
B	831	3	105.9
C	831-1	2	87.6
C	PC10B	2	81.5
D	831-1	1	129.2
E	831-1	4	145.7
F	831-1	3	157.1
G	831-1	1	167.2
H	831-1	4	148.1
J	831-1	8	121.2
J	831-2	16	100.9
K	831-2	6	84.1

831 Target mean = 97.2

Average Tappet Weight Loss (ATWLorig): By Tappet Batch

SUCCESS TOGETHER



Tappet Batch	IND	Number of tests	Mean(ATWLorig)
A	831-1	3	102.6
A	PC10B	13	93.4
A	831	3	105.9
B	831-1	10	145.3
B	PC10B	1	89.3
C	831-1	12	130.2
C	831-2	16	100.9
D	831-2	6	84.1

831 Target mean = 97.2

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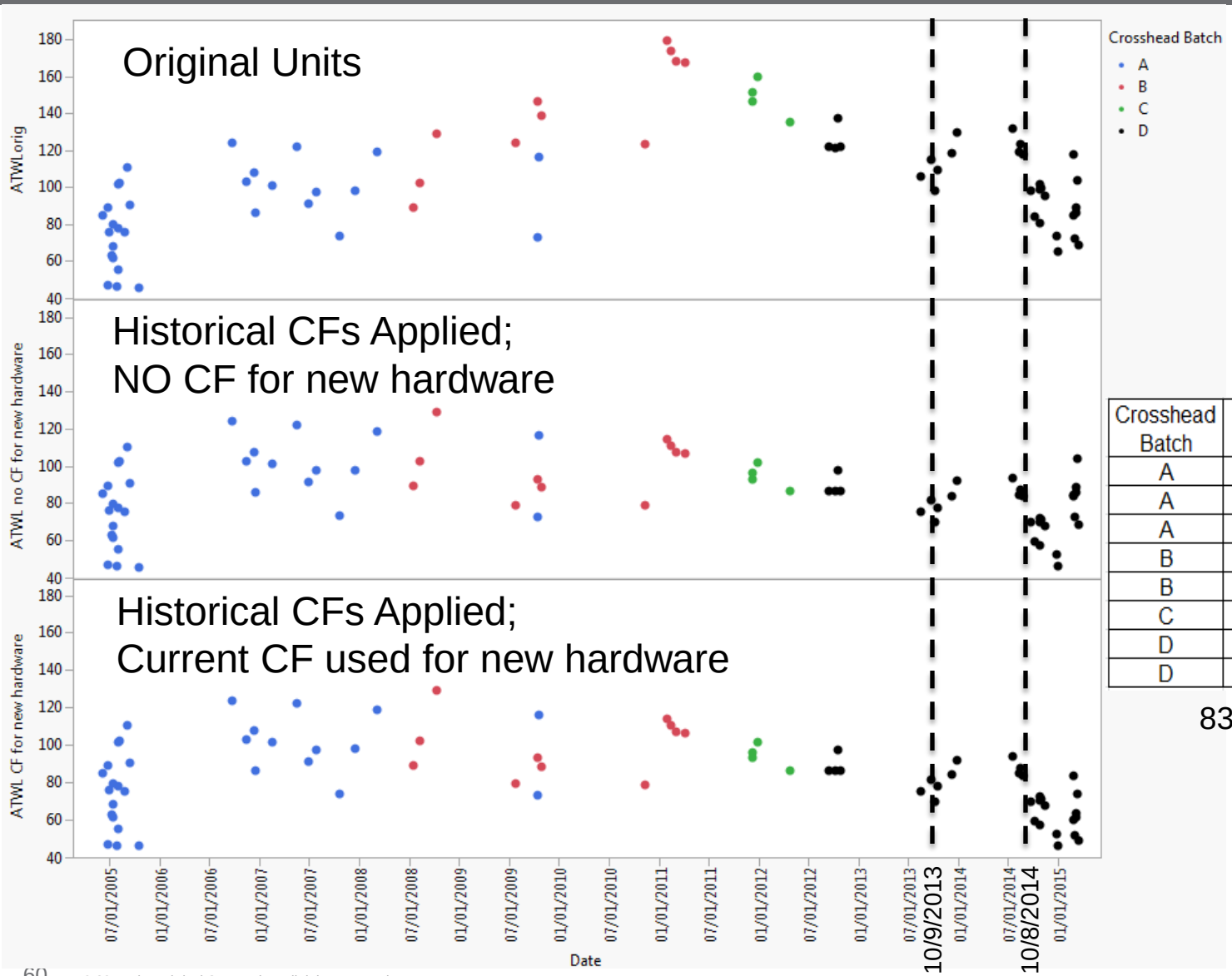
Average Tappet Weight Loss (ATWLorig): By Crosshead Batch

SUCCESS TOGETHER



Crosshead Batch	IND	Number of tests	Mean(ATWLorig)
A	831-1	3	102.6
A	PC10B	13	93.4
A	831	3	105.9
B	831-1	10	145.3
B	PC10B	1	89.3
C	831-1	4	148.1
D	831-1	8	121.2
D	831-2	22	96.4

831 Target mean = 97.2

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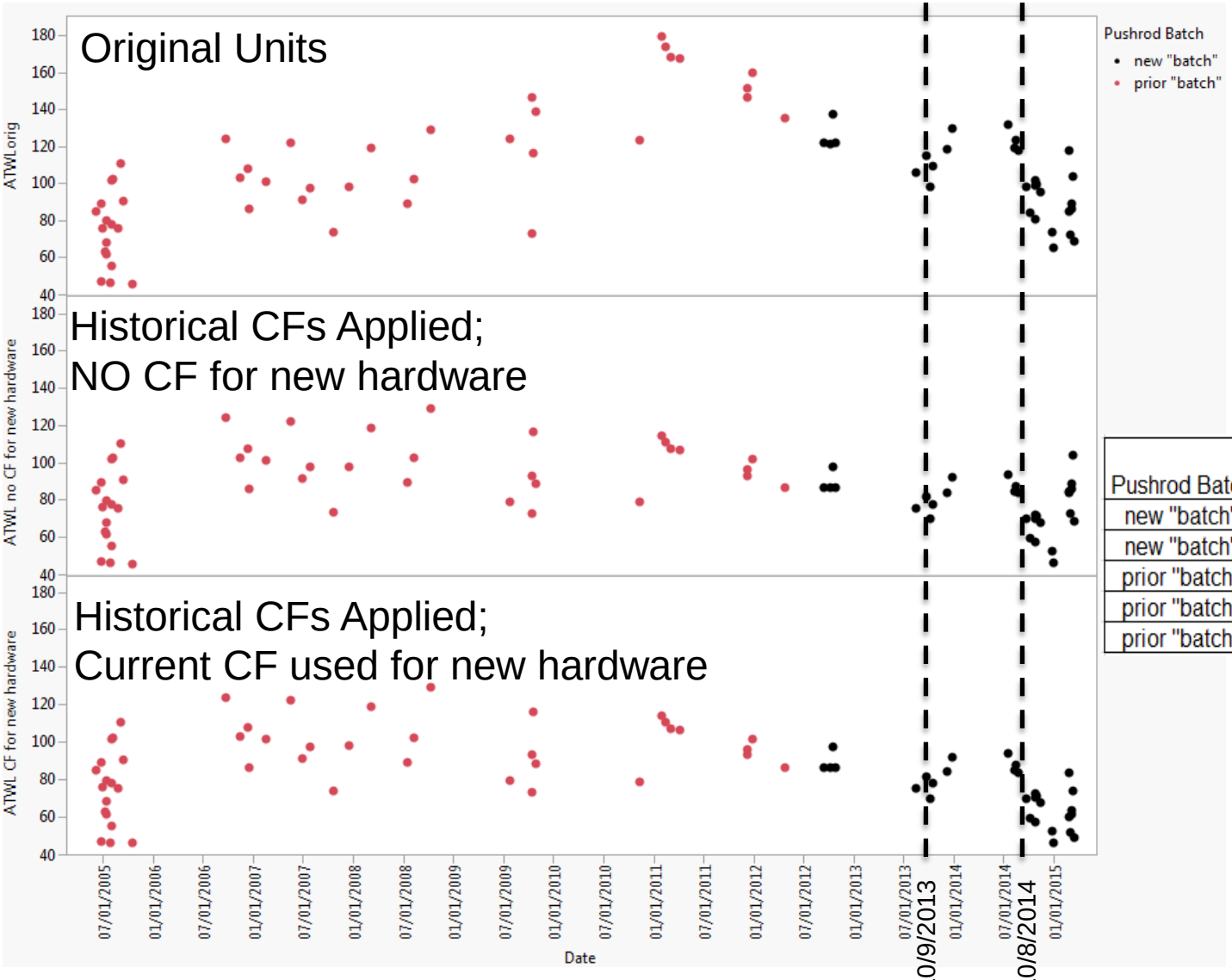
Average Tappet Weight Loss (ATWLorig): By Pushrod Batch

SUCCESS TOGETHER



Pushrod Batch	IND	Number of tests	Mean(ATWLorig)
new "batch"	831-1	8	121.2
new "batch"	831-2	22	96.4
prior "batch"	831-1	17	138.4
prior "batch"	PC10B	14	93.1
prior "batch"	831	3	105.9

831 Target mean = 97.2

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